Trace Elements in Seafood Organisms around Southern California Municipal Wastewater Outfalls

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TRACE ELEMENTS IN SEAFOOD ORGANISMS AROUND SOUTHERN CALIFORNIA MUNICIPAL WASTEWATER OUTFALLS

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Southern California Coastal
Water Research Project

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FOREWORD

This report describes work conducted under Standard Agreement No. 59H400 between the State Water Resources Control Board and the Southern California Coastal Water Research Project, as well as previous studies conducted by the contractor.

The optical emission spectroscopy analyses reported on were carried out at the Laboratory of Nuclear Medicine and Radiation Biology, University of California at Los Angeles, under the direction of Dr. George V. Alexander.

Printing and distribution of this publication were authorized by the State Water Resources Control Board on April 20, 1978. The findings reported are those of the contractor and do not necessarily reflect the opinion or policies of the State Water Resources Control Board.

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Contribution Number 106 of the Southern California Coastal Water Research Project.

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SUMMARY

1. Eight trace metals (silver-Ag, cadmium-Cd, chromium-Cr, copper-Cu, mercury-Hg, nickel-Ni, lead-Pb, and zinc-Zn) measured by atomic absorption spectrometry (AAS) in muscle tissue of six popular sportsfish caught near the Los Angeles County Joint Water Pollution Control Plant (JWPCP) and Orange County Sanitation District (OCSD) municipal wastewater outfalls were not concentrated significantly above levels measured in island and coastal control specimens.

2. In contrast, the edible portions of several invertebrate seafood organisms collected in the JWPCP discharge zone concentrated a number of these metals several-fold above natural levels. The largest contamination factors measured by AAS were for chromium in mollusks; median levels in muscle of black abalone and rock scallops were 10 times background. Muscle of crabs from around the outfalls typically contained 6 times as much nickel as occurs naturally, and levels of this metal in black abalone, rock scallops, and red sea urchin (gonads) were 2 to 3 times natural concentrations. Median muscle concentrations of silver in black abalone, rock scallop, and spiny lobster were approximately 3 times controls, and cadmium levels in rock scallops and spiny lobsters were 2 to 3 times controls. The JWPCP rock scallops also contained twice as much copper and mercury in their adductor muscle as did the island specimens; however, the mercury concentrations were an order of magnitude below the U.S. Food and Drug Administration (FDA) guideline of 0.5 mg/wet kg.

3. These findings are consistent with those obtained from an independent analytical technique, optical emission spectroscopy (OES). Intertidal mussels collected at the base of the JWPCP outfalls were found by OES to concentrate all of the target metals* except zinc above normal levels in the soft tissues (muscle, gonad, digestive gland, or "remainder"). Contamination factors for the latter three tissues for silver ranged from 4 to 8; for copper, from 2 to 4; for chromium, from 2 to 3. Corresponding factors for lead and tin in gonad tissue exceeded 3 and 8, respectively. In addition, mercury concentrations, measured by cold vapor AAS in muscle and digestive gland tissues of such mussels, averaged 4 times the levels found in island specimens. Again, the mercury levels were generally an order of magnitude below the FDA guideline.

4. The OES method also uncovered distinct metals contamination of mussels in two different types of harbors in the Bight. Specimens collected in Newport Harbor near a large vessel repainting facility contained levels of copper in four tissue classes that were 8 to 10 times those found in nearby coastal controls. PCB levels in these harbor mussels

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* Tin (Sn) was also concentrated above control levels.

were 9 times controls. Corresponding contamination factors for zinc ranged from 3 to 4, and for chromium, tin, and lead in gonadal tissue, the factors were 7, >18, and >13, respectively. All of these contaminants are, or have been, used extensively in various vessel-related materials such as bottom antifouling paints and primers or hydraulic fluids. Because recreational boating is the major activity occurring in Newport Harbor, this is strongly suspected to be the dominant source of the contamination. In San Diego Harbor, highest levels of copper and tin were measured near the commercial basin, the location of major vessel repainting and repair yards. In addition, polychlorinated biphenyl (PCB) concentrations in mussels from this site were 20 times above the coastal baseline. Further, abnormally high levels of cadmium were measured in mussels collected from the commercial docks.

5. Thus, the OES technique has been shown to be very valuable in locating regions of metals contamination through analysis of molluskan bioindicators such as intertidal mussels, which often contain relatively high concentrations of metals in tissues such as digestive gland and gonads. Analysis of standard reference materials revealed that the OES technique can be quite reliable for the measurement of metals in dry biological material of concentrations on the order of 1 mg/dry kg or above. In such cases, accuracy and precision values are generally better than ± 10 percent and ± 30 percent, respectively. However, below this level the accuracy and precision become questionable. Of seven metals (Ag, Cd, Cr, Cu, Ni, Pb, and Zn) measured in fish muscle intercalibration samples both by AAS and OES, acceptable agreement (± 25 percent) was obtained only for copper and zinc.

6. Despite the extreme contamination of bottom sediments by mercury around the JWPCP outfalls, with concentrations occurring up to two orders of magnitude above normal, six different species of benthic organisms (covering four phyla) showed no significant accumulation of this known toxicant in their body tissues. Levels found in muscle and liver tissue of Dover sole (means of 0.04 and 0.11 mg/wet kg) were in good agreement with results of earlier studies. Thus, it appears that the wastewater mercury that is carried to the soft bottom in this region is largely refractory and in a biologically unavailable state. In contrast, the filter feeding mollusks (rock scallop and byssal mussels) living on hard substrate inshore of the discharge, or cultured in the water column, apparently did concentrate mercury by factors of 2 to 4. However, levels in the outfall zone specimens were still an order of magnitude below the FDA guideline.

7. In general, rock scallops from the JWPCP zone depurated for one week in the laboratory lost less than half of a given metal from the three tissues analyzed. Major exceptions included digestive gland silver and gonadal zinc, for which median concentrations decreased by factors of 3.6 and 4.7, respectively. However, depuration did not appear to have any important effect on levels in the edible muscle tissue.

INTRODUCTION

The primary purpose of this investigation was to determine the degree to which seafood organisms accumulate trace metals above natural levels in the vicinity of submarine municipal wastewater outfalls. Two different types of discharge regions were selected for study. The first, the Joint Water Pollution Control Plant (JWPCP) outfall system (approximately 3 km in length) of the County Sanitation Districts of Los Angeles County (CSDLAC), has caused extensive contamination of bottom sediments off the rocky headlands of Palos Verdes Peninsula. For example, levels of cadmium, copper, and mercury in the surface sediments around the diffusers are up to 160, 20, and 80 times natural concentrations (Galloway, 1972; SCCWRP, 1973; Young et al. 1975). The second region is the discharge zone of the Orange County Sanitation District (OCSD) submarine outfall (approximately 8 km in length) off Newport Beach, where surface sediment concentrations generally do not exceed twice the estimated natural values (OCSD, 1977).

Seventeen species of common California seafood organisms were selected for study. These were divided into three groups (A, B, C). Those in the first group (A), whenever possible, were dissected into five tissue classes (muscle, gonad, liver, kidney, and skin) for trace element analysis; in contrast, only the edible portions of the species in Group B were analyzed. Group C originally contained two mollusks--the rock scallop and the pismo clam--of which the whole soft tissues were to be analyzed. However, owing to the relative scarcity of pismo clams in some of the study areas, and the importance of the intertidal mussel (Mytilus spp.) both as a pollution indicator and a potential food organism, this bivalve mollusk was substituted for the pismo clam. Because of the uncertainty in interpreting the meaning of whole body analyses in regions of high sediment contamination, it was decided to analyze separately the adductor muscle, gonad, and digestive gland of the rock scallops and intertidal mussels. In addition, depuration studies of the rock scallop were conducted in the Project laboratory. We had also hoped to determine elemental concentrations as a function of body and organ weight. However, not enough individuals of each species were collected to establish these correlations, and the sampling effort required to accomplish this was prohibitive.

In addition to the results of this state-supported seafood investigation, also included in this report are results of several other Southern California Coastal Water Research Project (SCCWRP) studies concerned with metals contamination of edible marine species. Together these results provide a large body of information on the degree to which nearshore marine organisms of southern California have been contaminated by metals from coastal municipal wastewater discharges, as well as by inputs from various harbor activities, another potentially significant source.

Finally, two different analytical techniques have been utilized and, where possible, compared. The first is optical emission spectroscopy (OES), which utilizes freeze-dried samples and thus provides results on a dry-weight basis. The advantage of this technique is that a relatively large number (26) of elemental determinations can be made simultaneously and at very low cost on biological material without prior chemical processing. Thus, this method could provide an extremely useful capability for rapidly scanning a variety of elemental pollutants in marine organisms. The second technique is atomic absorption spectroscopy (AAS), which utilized wet samples and thus provides results on a wet-weight basis. Although this method permits only one determination at a time, on chemically processed samples, it is extremely sensitive. An extensive summary of dry:wet-weight ratios is provided within the report to permit cross comparisons of results from these two techniques. Also, both medians and means are utilized in this report, depending on our judgment as to which best represents the central tendency of data in a given study.

1. 1975-1976 Seafood Studies

1.1. Materials and Methods

Figure 1 illustrates the locations of the four major regions covered in this part of the study. These regions are (1) the municipal wastewater discharge zone of the JWPCP submarine outfall system, located off Palos Verdes Peninsula; (2) the municipal wastewater discharge zone of the OCSD submarine outfall, located off Newport Beach; (3) the waters around Santa Catalina Island, selected as the Island Control site; (4) the coastal waters off Point Dume (at the northern end of the Santa Monica Bay), Dana Point, and La Jolla (north of San Diego City), selected as the Coastal Control sites.

In order to maximize the degree of coverage (up to seventeen species from each of the four wastewater or control regions), advantage was taken of all available sampling efforts of SCCWRP and of the CSDLAC and OCSD agencies. During 1975 and 1976, a total of 92 days at sea were required to collect the 378 organisms that were analyzed. This effort included 35 days to collect the 130 "JWPCP" organisms from the Palos Verdes Shelf; 18 days for the 88 "OCSD" organisms from off Newport Beach; and 25 days for the 104 "Island Control" organisms. In addition, considerable sampling effort was expended for other SCCWRP programs in the 1974 collections of coastal and harbor intertidal mussels and coastal rock scallops, and the 1976 collections for analysis of mercury in bottom organisms and "buoy mussels" from the JWPCP discharge zone (discussed in subsequent sections).

Table 1 lists the organisms collected in the 1975-1976 Seafood Studies, by group. Five methods of collection were used: bottom trawl, trap, hook and line, spear, and handtools (Appendix B, Table B-1). Individuals which could have been contaminated during collection (eg., by puncture of the gut cavity) were rejected. Each organism was rinsed with clean seawater prior to being placed in plastic bags. Freezers or dry ice containers were available so that the organisms could be immediately frozen. These organisms remained frozen until they were dissected for analysis by atomic absorption spectroscopy or optical emission spectroscopy.

1.2. Results

To evaluate the utility of optical emission spectroscopy for seafood contamination investigations, an intercalibration program was conducted between the optical emission spectroscopy laboratory at the University of California, Los Angeles, and SCCWRP's Atomic Absorption Spectroscopy laboratory. Replicate specimens of five fish species were sampled for the edible white muscle tissue, and gonadal and liver tissue.

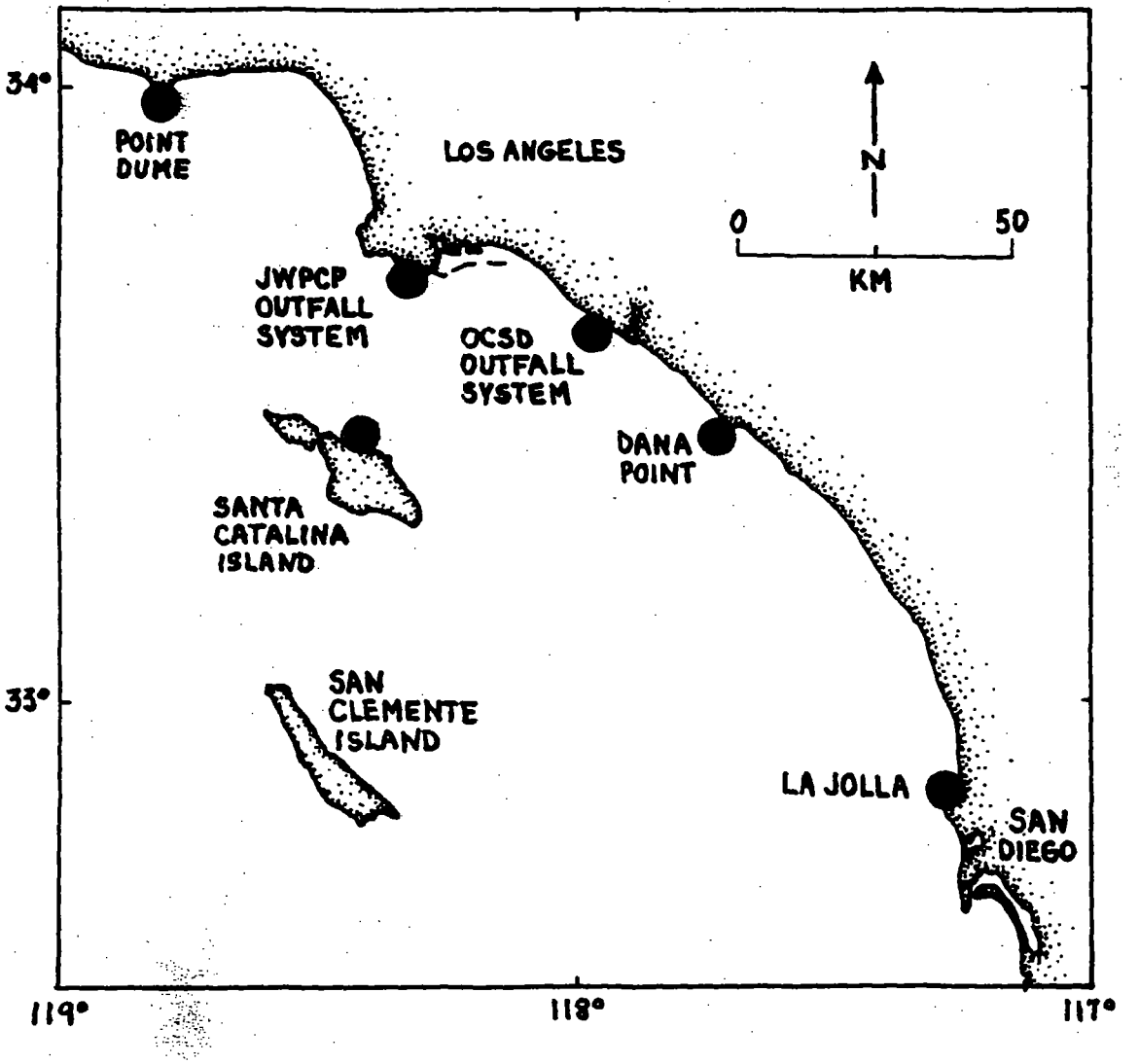

Figure 1. Sampling regions for 1975-76 seafood collections.

Table 1. List of Organisms Collected, by Group

GROUP	ORGANISM	GENUS SPECIES
A	Black Abalone	Haliotis cracherodii
	Ca. Spiny Lobster	Panulirus interruptus
	Bocaccio	Sebastes paucispinis
	Ca. Halibut	Paralichthys californicus
	Ca. Scorpion Fish	Scorpaena guttata
	Kelpbass	Paralabrax clathratus
	White Croaker	Genyonemus lineatus
B	Red Sea Urchin	Strongylocentrotus franciscanus
	Ridgeback Prawn	Sicyonia ingentis
	White Squid	Loligo opalescens
	Yellow Crab	Cancer anthonyi
	Barred Sandbass	Paralabrax nebulifer
	Northern Anchovy	Engraulis mordax
	Pacific Bonito	Sarda chiliensis
	Pacific Sanddab	Citharichthys sordidus
C	Rock scallop	Hinnites multirugosus
	Intertidal Mussel	Mytilus californianus
	Bay Mussel	Mytilus edulus

These thirty samples were lypholized (freeze-dried) overnight, and 10 dry mg of each was analyzed by OES, while approximately 1 dry gm was analyzed by AAS. Further details regarding sample preparation and analytical methods are presented in Appendix A. The results are presented in Appendix B, Table B-2. Typical dry:wet weight ratios measured for the various organisms and tissues covered in this study are presented in Appendix B, Table B-3.

The results presented in Table B-2 indicate that the OES technique lacked the necessary sensitivity to detect and quantify a number of the metals measurable in fish tissues by AAS. Therefore, wherever possible triplicate specimens of eleven of the fifteen species in Groups A and B were selected from each of the four study areas for AAS analysis of seven metals (Ag, Cd, Cr, Cu, Ni, Pb, Zn) in the edible tissue (muscle tissue in all cases except the red sea urchin, where gonad was analyzed instead). Rock scallops collected during 1974 from the JWPCP (n=8) and Island Control (n=6) areas had been analyzed previously in the Project's AAS laboratory. Thus, the AAS program covered twelve of the seventeen species of this study. These included six invertebrate seafood organisms and six seafood fishes (listed below, along with their typical diet - J. Allen, pers. comm.)

Common Name	Typical Diet
Invertebrates	
Red Sea Urchin	Algae
Black Abalone	Algae
Rock Scallop	Phytoplankton
Ridgeback Prawn	Detritus
Yellow Crab	Detritus
California Spiny Lobster	Detritus
Fishes	
White Croaker	Polychaete Worms
Pacific Sanddab	Crustaceans
California Scorpionfish	Crustaceans and molluscs
California Halibut	Fish
Bocaccio	Fish
Kelp Bass	Fish

In some cases, the copper and zinc values were obtained from OES analyses of these samples by converting from a dry to a wet weight basis and dividing by the median OES/AAS intercalibration ratios discussed in the following section (1.25 for Cu; 0.84 for Zn). In addition, this report includes mercury analyses of muscle tissue from all seventeen target species. Table B-4a (Appendix B) lists the

median and range of the three values for the wet weight muscle tissue concentrations of the seven metals measured by AAS in the available 1975-1976 seafood collections; corresponding mercury concentrations (median and range for two to ten specimens per area) are listed in Table B-4b.

The OES portion of this seafood study generated more than 20,000 individual tissue concentrations for the twenty-five major and minor elements available to this technique. To reduce this very large body of information to a manageable level, we have selected for presentation and analysis the seven trace metals (Ag, Cd, Cr, Cu, Ni, Pb, Zn) which we consider to be of greatest pollution concern. All of the OES data generated under this contract have been supplied as a separate appendix to the California State Water Resources Control Board.

For each tissue of each species analyzed from each available study area, the number of specimens measured (n), and the median and range of dry weight concentrations, are presented in Appendix B, Table B-5.

1.3. Discussion

As is shown in Appendix A, the OES technique is quite reliable for the measurement of copper, manganese, nickel, lead, and zinc (and very possibly other trace metals not yet certified by NBS) in dry biological material at concentrations on-the-order-of 1 mg/kg (approximately 4 mg/wet kg) or above. Accuracy and precision values are generally better than ± 10 percent and ± 30 percent, respectively. However, below this level the accuracy and precision becomes questionable.

For example, the average determinations of cadmium at the 0.1-0.3 mg/dry kg level in the Bovine Liver and Orchard Leave Standard Reference Materials by OES exceeded the National Bureau of Standard values by factors of 6 to 7, and the relative standard deviations exceeded ± 60 percent. In addition, the results of the intercalibration study listed in Table B-2 indicate that, of the seven metals compared in the samples of fish muscle, gonad, and liver, four (Cd, Cr, Ni, and Pb) generally were not quantifiable by the OES technique. For the other three (Ag, Cu, and Zn), we have calculated the ratio of concentrations determined by OES and AAS for the 10 comparisons in each tissue class, and determined the median ratios as shown below:

Median Ratio: OES/AAS

Tissue	Ag	Cu	Zn
Muscle	6.0	1.25	0.84
Gonad	2.8	1.12	0.78
Liver	2.8	1.18	0.48

These results indicate generally satisfactory agreement, on the average, between the two methods for copper and zinc in these tissues (with the possible exception of the factor-of-two discrepancy for zinc in liver). It appears that there is a distinct bias between the methods in the case of silver, with the OES method yielding values 3 to 6 times those of the AAS method, on the average. The reason for this difference is not known, but two obvious potential causes are spectral interference in the OES analyses for silver, or loss of this metal from the sample solution prior to analysis by AAS. Thus, we conclude that, of the seven trace metals included in this intercalibration study, at the relatively low concentrations generally observed in seafood (i.e., muscle tissue) samples, the OES technique is generally useful only for the determinations of copper and zinc. However, as will be shown in subsequent sections, this method is very useful in providing scans of a variety of pollutant metals in marine indicator tissues such as the digestive glands of intertidal mussels.

In order to facilitate a comparison of the AAS data presented in Table B-4, we have listed in Table 2 median values for muscle tissue of six invertebrates* and six fishes judged to be most useful. These data show that very low concentrations of the target trace metals generally occur in muscle tissue of the fishes investigated. Many of the values listed are an order of magnitude below those recently reported from an extensive study of metals in muscle tissue of fishes from the Mediterranean Sea, off Israel (Table 3). The reason for this difference is not known. Our values also are usually within the range of concentrations reported for five other studies of fishes from the North Atlantic and South Pacific (Table 4). It does not appear that the specimens living in the vicinity of the JWPCP or OCSD municipal wastewater discharges had accumulated these metals significantly above natural levels.

In contrast, it appears that certain of the invertebrates from the JWPCP outfall zone concentrated a number of these metals to levels 2 to 3 times those occurring in the control zone specimens. An insufficient number of invertebrate specimens were obtained in the OCSD zone to allow comparison. For example, median values for silver in muscle tissue of the abalone, rock scallop, and spiny lobster collected near the JWPCP discharge were approximately 3 times those observed in the control specimens. Similarly, the concentrations of cadmium in muscle of the JWPCP rock scallops and lobsters were 2 to 3 times those measured in the controls. The JWPCP rock scallops also appeared to contain somewhat more than twice as much copper and mercury in their adductor muscle as did the Santa Catalina Island specimens. However, the values for the latter metal were an order of magnitude below the 0.5 mg/wet kg limit of the U.S. Food and Drug Administration. Mercury is the only metal for which such a limit has been established. The JWPCP abalone, rock scallops, and red sea urchins also appeared to contain 2 to 3 times as much nickel as did the controls; for the yellow crab, median values were 6 times controls.

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* Gonadal tissue in the case of the sea urchin.

Table 2. Median concentrations (mg/wet kg) of eight trace metals in muscle tissue of twelve seafood organisms from southern California outfall and control sites, 1975-76.

Organism/Site	Ag	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Invertebrates								
Red Sea Urchin								
JWPCP	< 0.01	0.13	0.14	0.27	0.006	0.12	< 0.01	4.2
I. Control	< 0.01	0.44	0.18	0.26	0.024	0.04	< 0.01	11
Black Abalone								
JWPCP	0.03	0.04	1.0	3.4	0.011	0.68	< 0.12	13
I. Control	< 0.01	0.03	0.10	3.9	0.009	0.20	< 0.08	7.1
Rock Scallop								
JWPCP	0.022	0.92	0.31	0.29	0.056	0.22	< 0.03	24
I. Control	0.006	0.33	< 0.03	0.11	0.025	0.10	< 0.03	22
Ridgeback Prawn								
JWPCP	< 0.01	0.03	< 0.02	2.0	0.080	< 0.03	< 0.01	9.8
OCSD	0.02	0.06	0.12	8.0	0.040	< 0.04	< 0.12	13
C. Control	< 0.01	0.04	0.02	ND*	0.046	0.04	0.16	ND
Yellow Crab								
JWPCP	0.10	< 0.01	0.08	7.9	0.034	0.26	0.14	25
C. Control	0.22	0.01	0.04	13	0.071	< 0.04	< 0.15	97
Spiny Lobster								
JWPCP	0.05	0.02	0.03	6.1	0.28	< 0.05	< 0.23	8.6
C. Control	0.02	< 0.01	0.04	6.4	0.28	< 0.05	< 0.20	11
I. Control	0.01	< 0.01	< 0.02	14	0.25	< 0.06	< 0.21	14

* ND = No Data.

Table 2 Cont.

	Ag	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Fishes								
White Croaker								
JWPCP	0.02	<0.01	0.06	0.21	0.048	0.42	0.29	3.6
OCSD	0.03	<0.01	0.06	0.17	0.18	0.16	0.41	3.0
C. Control	0.02	<0.01	0.02*	0.11	0.33	0.61	0.71	1.3
Pac. Sanddab								
JWPCP	<0.01	<0.01	0.03	0.20	0.095	0.06	0.02	3.2
OCSD	<0.01	<0.01	0.03	0.09	0.11	0.05	0.03	2.0
C. Control	<0.01	<0.01	0.02	ND**	ND	0.04	0.28	ND
I. Control	<0.01	<0.01	0.06	0.17	0.072	0.08	0.24	3.9
Ca. Scorpionfish								
JWPCP	0.02	<0.01	0.04	0.15	0.38	0.15	0.64	3.8
OCSD	0.02	<0.01	0.07	0.10	0.28	0.85	2.0	4.0
C. Control	0.02	<0.01	0.04	0.15	0.24*	0.11	1.1	1.9
Ca. Halibut								
JWPCP	<0.01	<0.01	<0.01	0.13	0.25	<0.02	0.01	2.8
C. Control	<0.01	<0.01	<0.02	<0.02	0.22	<0.01	0.01	2.4
Bocaccio								
JWPCP	<0.01	<0.01	<0.01	0.15	0.14	0.06	0.08	4.3
OCSD	<0.01	<0.01	0.02	ND	0.13	0.04	0.20	ND
I. Control	<0.01	<0.01	0.01	0.13	0.32	<0.05	<0.08	1.8
Kelp Bass								
OCSD	<0.01	<0.01	0.02	0.19	0.36	0.06	<0.01	3.7
I. Control	<0.01	<0.01	0.02	0.13	0.43	0.04	<0.01	4.0

* Island Control
**ND = No Data.

Table 3. Trace metals in fish from Mediterranean coastal waters off Israel (Table VII of Roth and Hornung, 1977).

Species	Collection date (1974)	Area + depth (fms)	Mean total length (cm)	Mean weight (g)	No. of individuals analyzed	Dry weight (%)	Concentration (ppm/dry weight)					
							Cd	Pb	Cu	Zn	Ni	Cr
Sardinella aurita	4 Sept	Haifa Bay	17.0	42	16	24.8	0.6	0.6	3.4	81.6	2.3	3.4
		off Qishon R.	18.5	56	7	25.1	0.6	0.7	6.0	84.3	2.3	3.4
	9 Sept	Haifa Bay	11.2	14	8	29.7	0.6	0.4	4.7	61.3	2.6	2.2
		14	13.5	21.5	30	31.8	0.6	0.3	2.8	40.2	1.6	2.1
			17.2	50	4	26.8	0.5	0.5	4.9	78.6	3.4	2.5
Saurida undosquamis	25 Mar	Haifa Bay	26.0	116	4	25.4	0.3	2.8	1.3	5.3	2.9	1.4
		14	28.8	127	3	25.4	0.3	2.7	0.9	0.5	6.3	1.2
			30.5	230	1	24.4	0.4	2.8	0.7	5.0	10.8	1.7
			33.0	271	1	24.4	0.4	3.2	3.9	7.7	1.5	1.7
	13 Jun	South coast	20.2	62	10	24.1	0.3	2.7	6.4	32.1	2.4	2.2
		16	27.5	150	4	24.5	0.3	2.5	2.5	20.2	1.2	0.9
	7 Sept	South coast	24.2	43	3	24.3	0.2	0.3	2.0	20.5	0.3	0.6
		20	26.8	140	4	24.0	0.2	0.3	2.5	32.2	0.8	0.8
			31.8	238	3	23.2	0.2	0.4	2.4	20.8	0.9	1.0
Merluccius merluccius	6 Mar	Central coast	21.5	70	2	20.5	0.2	2.6	5.2	26.8	nd*	2.2
		40	24.5	128	2	21.4	0.2	4.4	2.9	7.9	0.1	2.3
			26.5	157	3	21.4	0.3	2.7	3.8	2.7	0.2	2.7
			31.5	276	1	21.4	0.3	4.8	3.1	12.7	1.0	2.3
Epinephelus aeneus	26 Jul	Central coast	48.0	1200	1	23.3	0.1	0.04	5.4	33.0	1.6	
		27										
	28 Aug	South of Haifa Bay	36.0	556	1	23.1	0.2	0.3	2.6	21.7	1.1	1.0
		70										
	28 Aug	Haifa Bay	37.0	614	1	21.5	0.2	0.3	2.6	23.3		
		14										
Epinephelus guaza	8 Sep	Central coast	60.0	2150	1	18.8	0.1	0.3	3.3	25.5	0.8	2.4
		30										
Mullus barbatus	6 Mar	Central coast	16.0	54	18	20.4	0.7	3.4	6.4	14.9	1.4	2.8
		48										
	13 Jun	South Coast	11.0	30	2	21.4	0.6	3.2	4.2		1.6	4.9
		16										
	7 Sep	South coast	14.0	32	10	24.7	0.2	0.4	5.3	22.0	1.8	2.9
		20										
Upeneus moluccensis	6 Mar	South coast	17.5	62	5		0.3	5.3	5.0	23.1	0.7	4.1
		10										
	13 Jun	Haifa Bay	16.5	48	3	27.0	0.4	2.9	8.3	27.2	1.6	2.0
		30										
	1 Sep	South coast	14.5	35	10	23.8	0.2	0.3	4.5	25.1	1.7	2.3
		20										
Diplodus vulgaris	1 Aug	Central coast	18.9	133	6	23.4	0.3	0.3	4.2	26.5	1.7	1.0
		8										
Sphyraena sphyraena	20 May	Haifa Bay	31.5	108	4	26.8	0.3	5.2	23.5	20.7	0.1	2.0
		5	40.5	285	2	24.5	0.3	1.8	4.8	20.2	0.5	1.7
Siganus rivulatus	8 Sep	Central coast	24.5	236	10	25.1	0.2	0.3	3.1	25.8	0.7	1.4
Solea solea	7 Sep	South coast	20.5	62.7	10	23.6	0.2	0.3	1.4	22.1	1.1	1.1
		20										

* nd = not detected.

Table 4. Heavy metal levels (mg/kg) of commercial fish in catches from coast of Israel and other selected areas. (After Table VIII of Roth and Hornung, 1977.)

Location		Cd	Pb	Cu	Zn	Ni	Cr
Israel, range	Dry wt	0.1-0.7	0.04-5.3	0.7-8.3	0.5-84.0	ND*-10.8	0.6-4.9
(Roth and Hornung, 1977)	Wet wt	0.02-0.17	0.01-1.3	0.17-2.0	0.1-20.3	ND -2.6	0.14-1.2
Israel, mean	Dry wt	0.33	1.8	3.8	27.2	1.8	2.1
(Roth and Hornung, 1977)	Wet wt	0.08	0.4	0.9	6.6	0.4	0.5
Scottish waters	Dry wt						
(Topping, 1973)	Wet wt	0.03-0.12	<0.2-1.2	0.05-4.3	1.6-23.0		
England and Wales	Dry wt						
(Portman, 1972)	Wet wt	<0.05-0.16	0.5-1.0	0.5-1.8	4.4-6.6		<0.5-0.6
North Atlantic	Dry wt	<0.1-2.1		1.5-3.2	8.0-20.0		
(Windom et al. 1973)	Wet wt						
Northeast Atlantic	Dry wt	0.05-0.98			44		
(Leatherland et al. 1973)	Wet wt						
New Zealand	Dry wt						
(Brooks and Ramsey, 1974)	Wet wt	0.001-0.2	0.04-1.6	0.03-3.4	0.9-56.0	0.01-0.1	0.01-0.05

* ND = not detected.

The greatest accumulation of chromium was found in the muscle of abalone and rock scallops; in both cases the median concentrations in the JWPCP specimens were 10 times those measured in the animals collected from Santa Catalina Island. In themselves, chromium concentrations of this magnitude (1 mg/wet kg in the abalone and 0.3 mg/wet kg in the scallop) would not be expected to reduce the value of these shellfish as a seafood resource--several surveys of the U.S. nutritional situation have indicated that marginal deficiency of chromium in the diet is of greater concern than overexposure (National Academy of Science 1975). However, shellfish from the outfall area may contain other contaminants (such as chlorinated hydrocarbons) that are known to be detrimental to human health and that are often concentrated in benthic organisms living in outfall areas (Young et al. 1976; McDermott et al. 1976). In addition, the form of the chromium in the shellfish--a nutritionally important factor--is not known.

The OES results for the seven target metals listed in Table B-5 are based on almost 6,000 individual concentration values covering forty-five species-tissue classes for the specimens collected from the four study regions. However, as discussed above, the levels of cadmium, chromium, nickel, and lead in our samples generally were below the detection limit of the OES technique utilized in this study. Therefore, we have limited our statistical analysis of these data to the results for silver, copper, and zinc.

The purpose of this analysis was to determine if, for each of these three metals measured in the various organisms and tissues, there were statistically significant differences between any two of the study regions. Thus, for the metal being tested, median concentrations for the species-tissue classes which were available for both of the regions being compared were analyzed as a group by the rank-sum test (Tate and Clelland, 1957). This is a nonparametric test which is designed specifically for paired data--in this case the common factor between the two regions (for the specified metal) being a given species and tissue. This procedure, covering three metals and four study regions (PV-JWPCP;OC-OCSD; CC-Coastal Control; IC-Island Control) resulted in a total of eighteen individual statistical tests. The two-tailed "p" values (i.e., the probability that levels of the given metal in comparable organisms and tissues from the two regions were not different) are listed in the matrices below; also shown are the number (n) of pairs on which each test is based.

	Silver				Copper				Zinc			
	P.V.	O.C.	C.C.	I.C.	P.V.	O.C.	C.C.	I.C.	P.V.	O.C.	C.C.	I.C.
P.V.	-	$p>0.20$ (17)	$p>0.20$ (18)	$p>0.20$ (22)	-	$p>0.20$ (22)	$p>0.20$ (20)	$p>0.10$ (23)	-	$p>0.20$ (21)	$p>0.20$ (21)	$p>0.10$ (27)
O.C.		-	$p>0.20$ (9)	$p>0.20$ (10)		-	$p>0.20$ (12)	$p>0.20$ (12)		-	$p>0.20$ (20)	$p>0.20$ (13)
C.C.			-	$p>0.05$ (14)			-	$p>0.20$ (12)			-	$p>0.20$ (14)
I.C.				-				-				-

P.V. = Palos Verdes
O.C. = O.C.S.D.
C.C. = Coastal Control
I.C. = Island Control

These results show that, for silver, copper, and zinc, at the 95 percent level of confidence ($p<0.05$), no statistically significant differences were observed between any of the six possible region pairs. Although sufficient data did not exist to justify extension of these tests to the other four target metals, examination of the available results for cadmium, chromium, nickel, and lead listed in Table B-5 does not suggest any systematic regional differences between levels of these metals in comparable tissues. These findings are consistent with those of the AAS muscle tissue study, which suggested that the (generally small) tissue concentration elevations observed in the JWPCP samples were limited to a minority of the species examined.

2. 1974 Rock Scallop Studies

2.1. Materials and Methods

During 1974, divers collected eight rock scallops 10 to 25 cm in diameter from depths of about 15 m at three stations in the discharge zones between Whites Point and Point Vicente, less than 1 km off Palos Verdes Peninsula. Six rock scallops also were taken from control stations at similar depths off Santa Catalina Island (Figure 2). The samples were frozen in plastic bags upon collection. Later, digestive gland, gonad, and adductor muscle tissues were excised from each specimen before it was fully thawed; the tissues then were placed in acid-washed, plastic vials. Care was taken to avoid contaminating the gonadal or muscle tissue samples with sediments or juices from the digestive glands. These samples were subsequently analyzed by atomic absorption spectroscopy.

2.2. Results

Table 5 presents median and mean concentrations of seven metals in the tissues of the eight rock scallops from the JWPCP study area and the six specimens from the island control area. A comparison of the medians and means (which have an average ratio of 0.93 ± 0.07 at the 95 percent confidence limit) suggests that the distributions of concentrations of most metals are not highly skewed.

2.3. Discussion

The data presented in Table 5 clearly illustrate that, during 1974, rock scallops living inshore of the JWPCP discharge were accumulating trace metals above normal levels: sixteen of the nineteen contamination ratios are greater than 1.0. The ratios for chromium are the largest (19, 6.7, and 7.0 for digestive gland, gonad, and adductor muscle, respectively), and the standard error values listed indicate that these differences are statistically significant.

In our past studies with molluskan bioindicators, we have generally used digestive gland concentrations to locate possible metals contamination because concentrations are usually higher in this tissue than in the gonad or adductor muscle (Alexander and Young 1976; Eganhouse and Young 1976). However, these values may not be representative of the degree to which metals are actually incorporated into the body tissues, because the digestive gland sample may contain ingested particulates contaminated by metals that are not biologically available. Therefore, the gonad and muscle contamination ratios found in this study are of special interest. Eleven of the twelve values exceed 1.0, and for each of the six metals measurable (lead was undetectable in these tissues), at least one of the two ratios is greater than 2.0. In addition, as shown above, the mean concentration (± S.E.) of total mercury measure in adductor muscle of three Palos Verdes rock scallops was 0.059 ± 0.013 mg/wet kg. This value

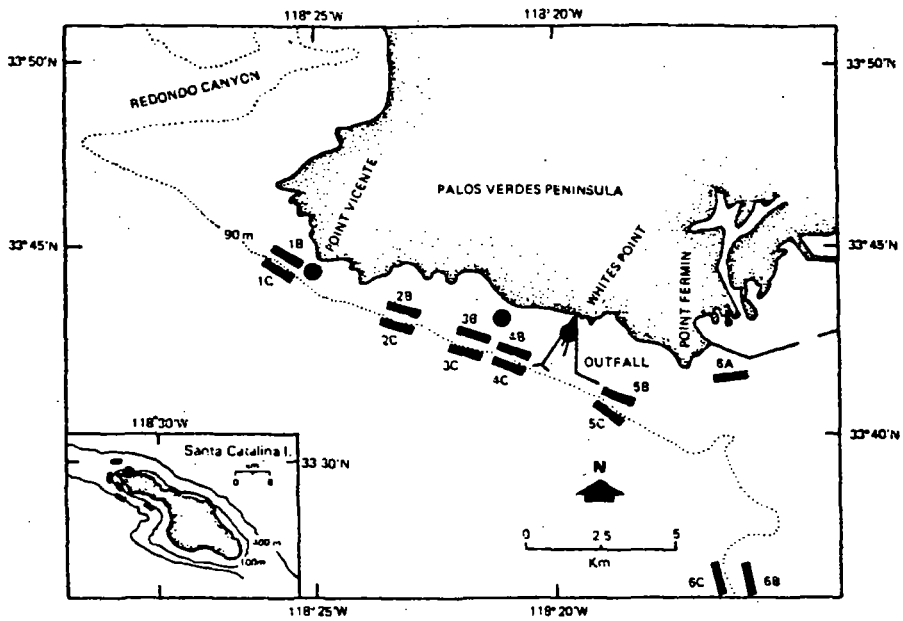

Figure 2. Palos Verdes and Catalina Island benthic trawl ▬ and 1974 rock scallop sampling stations ● .

Table 5. Trace metal concentrations (mg/wet kg) in tissues of the rock scallop Hinnites giganteus collected during 1974 from the JWPCP outfall zone and from Island Control stations.*

	Digestive Gland		Gonad		Adductor Muscle	
	Outfall	Control	Outfall	Control	Outfall	Control
Silver						
Median	2.3	0.26	0.075	0.015	0.022	0.006
Mean	2.3	0.31	0.080	0.018	0.026	0.008
±Std. Error	0.51	0.06	0.013	0.006	0.008	0.003
Cadmium						
Median	490	600	2.4	4.1	0.92	0.33
Mean	520	540	2.6	5.4	0.95	0.34
±Std. Error	89	54	0.42	2.1	0.11	0.03
Chromium						
Median	48	2.2	2.2	0.38	0.31	≤0.03
Mean	41	2.2	2.6	0.39	0.35	0.05
±Std. Error	8.0	0.43	0.31	0.05	0.05	0.02
Copper						
Median	170	48	3.3	1.9	0.29	0.11
Mean	190	64	3.2	2.2	0.41	0.16
±Std. Error	40	15	0.22	0.47	0.11	0.04
Nickel						
Median	1.3	1.4	0.30	0.15	0.22	0.10
Mean	1.3	1.5	0.42	0.26	0.22	0.12
±Std. Error	0.23	0.10	0.31	0.10	0.04	0.05
Lead						
Median	14	5.1	<0.06	<0.06	<0.03	<0.03
Mean	13	4.4	<0.06	<0.06	<0.03	<0.03
±Std. Error	3.1	1.3	-	-	-	-
Zinc						
Median	120	90	48	10	24	22
Mean	130	100	46	20	25	22
±Std. Error	15	17	6.3	6.5	1.6	0.65

* Values based on analyses of 8 rock scallops from the outfall area and 6 from island stations.

is more than twice the mean concentration measured in three island specimens (0.027 ± 0.020 mg/wet kg). However, it should be noted that the mercury levels in the Palos Verdes specimens were still an order of magnitude below the U.S. Food and Drug Administration guideline of 0.5 mg/wet kg.

As shown in Table 5, the mean concentration of lead in the digestive gland of the outfall rock scallops was 13 mg/wet kg, more than 200 times the upper limit concentration measured in the gonad (<0.065 mg/wet kg) and more than 400 times higher than the upper limit values for muscle tissue (<0.03 mg/wet kg). These results indicate that, to the first order, elevated concentrations measured in the gonad and muscle tissues were not caused by contamination from the digestive gland during dissection. Thus, rock scallops exposed to municipal wastewater from the JWPCP discharge appear to be physiologically incorporating at least seven of the trace metals of interest in their gonadal or muscle tissue to levels at least twice control concentrations.

3. 1974 Coastal Mussel Studies

3.1. Materials and Methods

During the summer of 1974, specimens of the intertidal mussel Mytilus californianus 4-6 cm in length were collected from fourteen coastal and five island stations in the Southern California Bight (Figure 3). These specimens were frozen in plastic bags until just before dissection, at which time composite samples of digestive gland, gonad, and adductor muscle were prepared from three specimens per collection site and analyzed for total mercury by cold vapor atomic absorption spectroscopy (CVAAS).

In addition to the analysis of total mercury in adductor muscle, gonad, and digestive gland from composites of three samples of M. californianus from the coastal and island stations shown in Figure 3, a separate experiment was performed to determine the variability in mercury levels of mussels collected at one location. For this study ten composite samples were prepared from specimens collected at Station 4.

3.2. Results

The results of the single-station variability studies are shown in Table 6. The levels of mercury in digestive gland appear to be somewhat less variable than those in the other tissues analyzed. Figure 4 presents the results for the three tissues from the general survey.

3.3. Discussion

The results illustrated in Figure 4 reveal a markedly similar pattern for each of the three tissues (digestive gland, gonad and muscle) of M. californianus collected from throughout the Southern California Bight. The highest levels of mercury were obtained for mussels found in Santa Barbara Harbor, (Figure 3, Station 3), just outside Oxnard Harbor (Station 5), in Santa Monica Bay (Station 7), on Palos Verdes Peninsula (Stations 8 and 9), and on Point Loma in San Diego (Station 14).

The elevated levels observed near the Santa Barbara and Oxnard Harbors are probably associated with vessel activities (e.g. sediment deposits of mercury-bearing antifouling paints). There are no large discharges of municipal or industrial wastewater in these regions. Mussels collected off Santa Monica Pier (Station 7) exhibited a higher concentration of mercury in digestive gland than the island control samples, but this trend was not found for the two other tissues. The enhanced level in digestive gland may reflect some influence of the Hyperion Treatment Plant (M 1), whose two municipal wastewater outfalls teminate at the head of Santa Monica submarine canyon. The high values in Palos Verdes and Point Loma specimens appear to be related to the submarine outfalls (M 2 and M 4) located in these areas. However, it is important to note

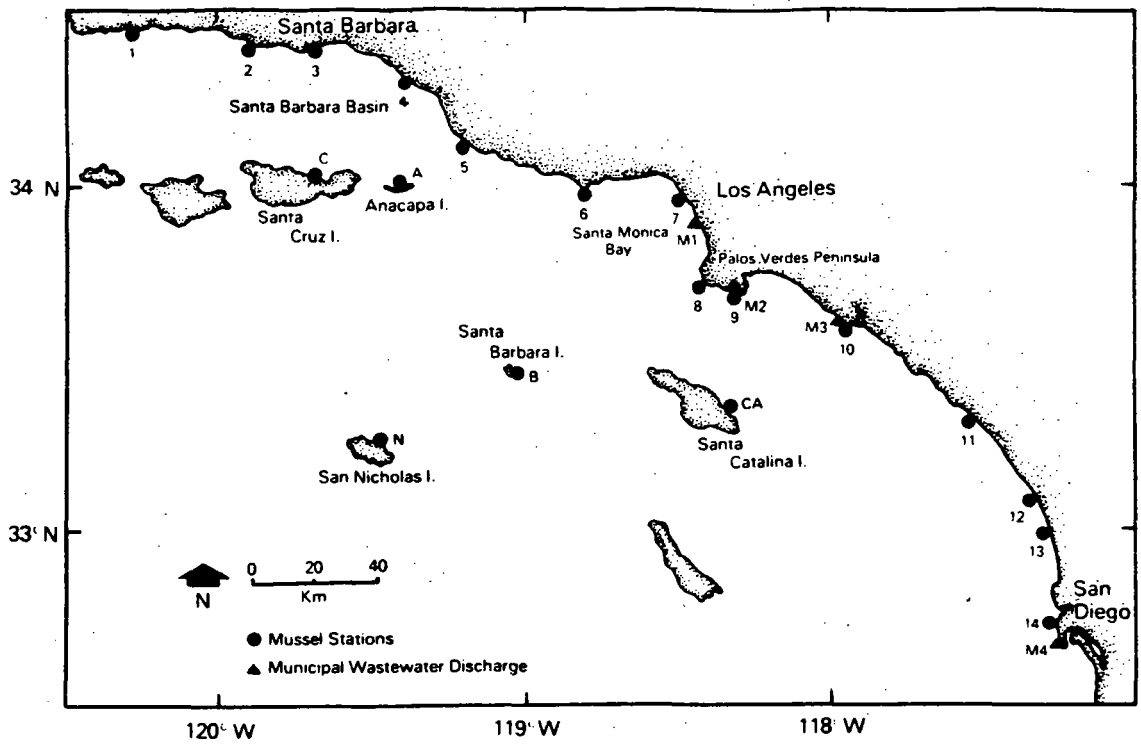

Figure 3. Station locations for 1974 coastal mussel survey. Four major municipal wastewater dischargers are: M1 (Hyperion, Los Angeles City), M2 (Los Angeles County), M3 (Orange County), M4 (Point Loma, San Diego City). From Eganhouse and Young, 1976.

Table 6. Concentration of total mercury (mg/wet kg) in tissues of coastal mussels from Emma Woods State Beach (see Figure 3, Station 4). From Eganhouse and Young, 1976.

Tissue	No. of samples	Total mercury Mean	Std. Error	Range
Adductor muscle	9	0.012	0.002	0.008-0.021
Gonads	8	0.005	0.001	0.002-0.010
Digestive gland	7	0.022	0.002	0.017-0.032

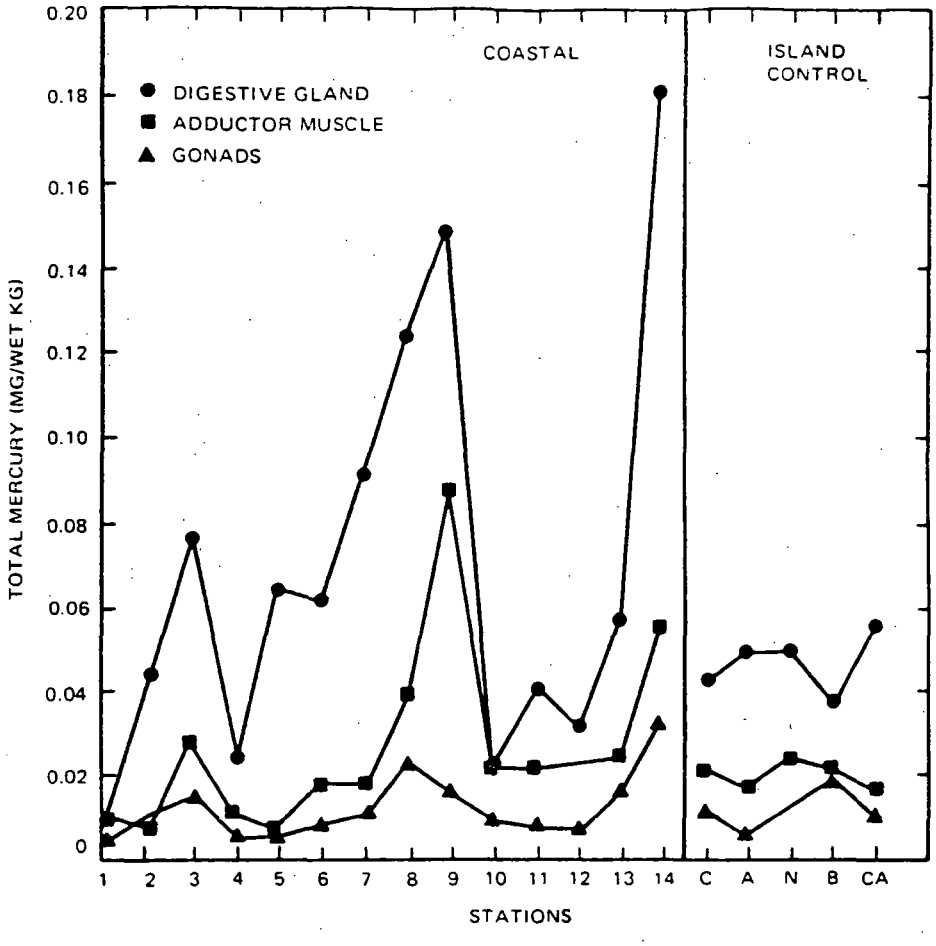

Figure 4. Total mercury content (mg/kg wet wt) in tissues of the intertidal mussel, M. californianus, collected at various coastal and island stations in 1974. See Figure 3 for station key. (From Eganhouse and Young, 1976.)

that these regions contain two major commercial and naval harbors, San Pedro Harbor (just east of Palos Verdes Peninsula) and San Diego Harbor, which are known to contain mercury-contaminated sediments (Chen & Lu, 1974; Barry, 1974) and therefore constitute possible sources of mercury to the local biota.

The digestive glands of the Royal Palms mussels (Station 9) contained 3.3 times the average levels of mercury found in the island samples. For adductor muscle and gonad tissues the ratios were 4.6 and 1.4, respectively. The ranges in values obtained for digestive gland, adductor muscle, and gonadal tissues were 0.011 to 0.18 mg/wet kg, 0.007 to 0.088 mg/wet kg, and 0.005 to 0.032 mg/wet kg, respectively. These levels are much lower, in general, than those reported by De Wolf (1975) for Mytilus edulis and M. galloprovincialis collected from west European coasts. The differences may be due to physiological factors of the test organisms, systematic differences between analytical techniques, and/or differences in the pollutant loads of the environment.

4. 1974 Harbor Mussel Studies

4.1. Materials and Methods

During January 1974, as part of a program sponsored by the California Department of Fish and Game, specimens of the intertidal mussel Mytilus edulis 4-6 cm in length were collected from several stations in and around three major southern California harbors: Los Angeles-Long Beach (San Pedro) Harbor, San Diego Harbor, and Newport Harbor (Figure 5). The first two harbors were chosen because of their importance as commercial and naval anchorages; Newport Harbor was selected because it shelters recreational vessels only, and receives no significant inputs of municipal, industrial, or surface runoff discharge. The sampling pattern was also designed to permit comparison of metals contamination levels between specimens from these harbors and from the coastlines inshore of the JWPCP and OCSD submarine discharges. The specimens were frozen in plastic bags until dissected. The whole soft tissues (excluding byssal threads) from three males and three females per station were separated into four categories--digestive glands, gonads, adductor muscle tissue, and the remainder. These portions of each individual mussel were freeze-dried separately for possible analysis by optical emission spectroscopy. The digestive glands from all six specimens from each station were subsequently analyzed; for the three other tissue classes, one male and one female per station were chosen for analysis.

4.2. Results

Table B-6a presents the average dry weight concentrations (plus or minus one standard error) of two trace metals, copper and cadmium, which appear to reflect distinct gradients in several tissues of the bay mussel M. edulis collected from six stations in or around San Diego Harbor. Corresponding average concentrations of eight trace metals (Ag, Cd, Cr, Cu, Ni, Pb, Sn, Zn) in the digestive glands of the six specimens from each of these stations are listed in Table B-6b. Table B-6c presents the average concentrations of these metals in the four tissues of specimens from the inner Newport Harbor station (Station I) located near a large vessel repainting and repair yard approximately 5 km from the Harbor entrance. Corresponding values for coastal specimens of the same species collected just across the spit at Station H, approximately 6 km inshore of the OCSD outfall diffusers, are also listed, along with the harbor-to-coastal ratios for these values. Table B-6d compares corresponding values for specimens from Royal Palms State Beach (located about 3 km inshore of the JWPCP outfall diffusers) with averages of these values for five other coastal stations Figure 5, Stations E, F, G, H, and J).

4.3. Discussion

The results of an earlier study (Young et al. 1974) indicated that approximately 180 m tons of copper are applied annually to vessel

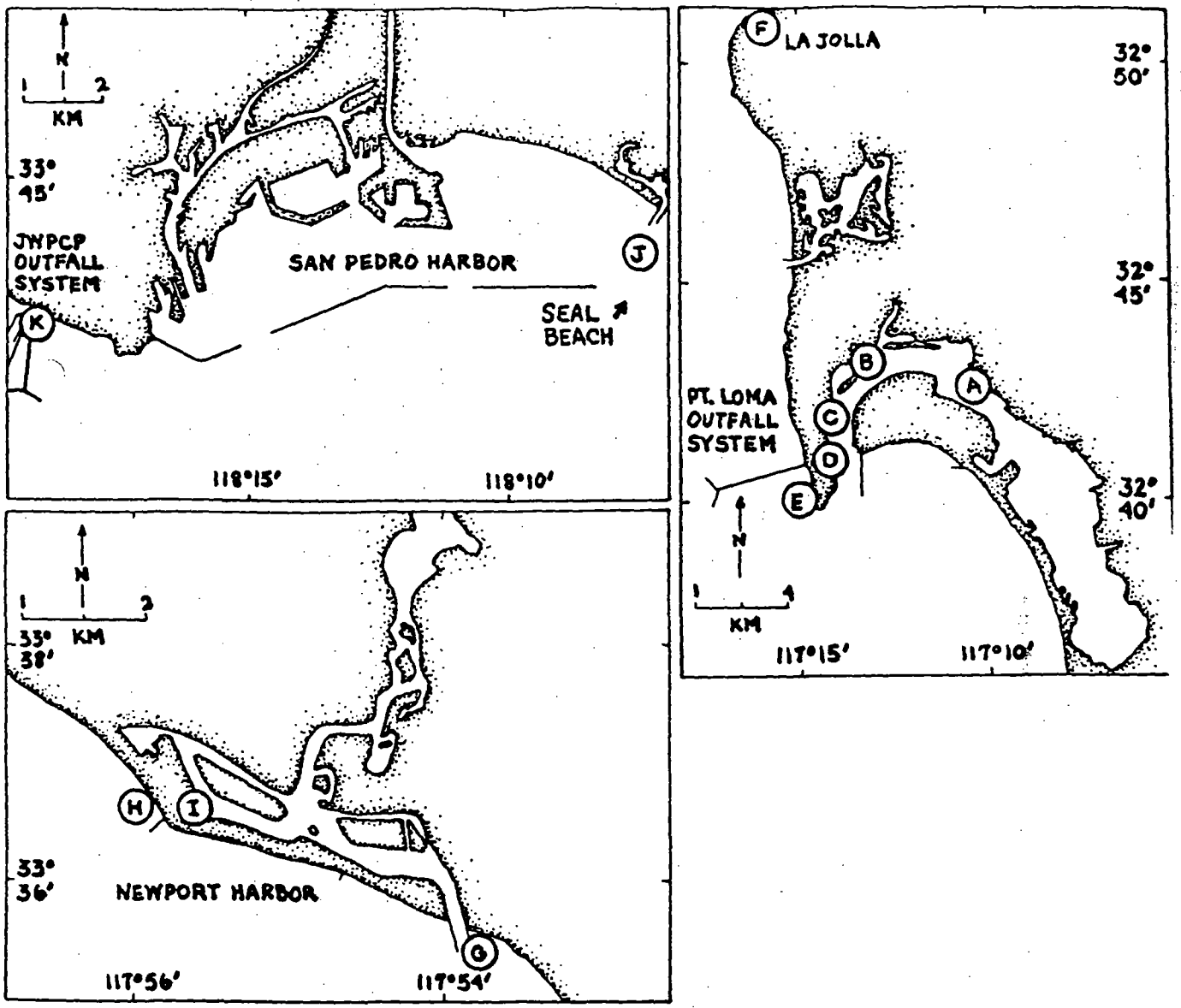

Figure 5. Harbor mussel collection sites, 1974.

bottoms in southern California; this is at least twice the estimated amount that enters the coastal ecosystem via storm runoff (about 40 m tons; Young et al, 1973) and aerial fallout (about 50 m tons; Young and Jan, 1977), and approximately one-third the amount discharged via coastal submarine outfalls (525 m tons; Schafer, 1976). In view of these results and the fact that the copper used in antifouling paints is specifically designed to be toxic to marine fouling organisms and to gradually slough off vessel bottoms (J.D. Isaacs, pers. comm.), it seems clear that the present use of high-copper antifouling paints is a potentially important input mode for this pollutant in nearshore marine waters.

The results of our study into trace metal concentrations in M. edulis from southern California harbors appear to reflect this copper input. The values listed in Table B-6a show that the highest concentrations of digestive gland copper in the San Diego Harbor survey occurred in mussels collected at the mouth of the commercial basin (Station B), where two large vessel repainting and repair yards are located. This was also true of the three other classes of tissues analyzed for copper. In addition, the whole soft tissues of specimens from this site had the highest concentrations of PCB 1254 measured in the San Diego collection (Young and Heesen, 1974). These data show that the copper values in all tissues analyzed in the commercial basin specimens were 2 to 4 times those in the specimens from most of the adjacent coastal sites. Further, the PCB values in mussel from the four Harbor stations were 6 to 20 times those for the two coastal stations.

High copper contamination has also been observed in bottom sediments from this area. Surface layer samples were collected during April 1974 from the major vessel repair yards in the commercial basin, and the four highest copper concentrations ranged from 1,400 to 5,500 mg/dry kg (Barry, 1974), compared to the estimated coastal baseline value of about 20 mg/dry kg (SCCWRP, 1973). These results suggest that the scraping and reapplication of high-copper (and, in the past, PCB-based) antifouling paints on vessel bottoms has significantly contaminated nearby bottom sediments and intertidal mussels.

Tin is another metal which is used as a toxicant in antifouling paints, and somewhat elevated levels of this metal also were observed in the digestive glands of the harbor specimens. As is seen from the data presented in Table B-6b, the average concentration measured at the four San Diego Harbor sites (Stations A-D) was 2.8 ± 0.4 mg/dry kg, compared to < 1.3 mg/dry kg for the two coastal sites (Station E - F). Although this difference was not statistically significant, it did suggest a trend that was also observed in Newport Harbor (discussed below).

One other anomaly was observed in the San Diego Harbor survey. The levels of cadmium in all four tissue classes of the specimens from the commercial docks (Station A) were distinctly higher than the average values for the five other stations in the region (Table B-6a). Three of the four tissues from the mussels collected at Station D near the Harbor mouth also appeared to have elevated cadmium. In addition, the commerical dock specimens had either the highest or second highest digestive gland concentrations of the seven other metals investigated in the San Diego Harbor region (Table B-6b). It should be noted that Station A is located deepest into the Harbor and also is exposed to inputs (such as surface wash-off) from the eastern half of North Island Naval Air Station. In view of the several potential sources of contaminants to this region, further study would be required to determine the causes of most of the elevated metal levels we have observed.

The highest levels of mussel contamination found in this study occurred in Newport Harbor. As is seen in Table B-6c, the average concentrations of copper in digestive glands from the Station I specimens (127 ± 18 mg/dry kg) were 8 times the value measured in the coastal specimens from Station H just across the spit (16 ± 1.0 mg/dry kg). Very similar contamination factors were observed for copper in the three other tissue classes (9.9, 9.1, 9.1) and also for PCB 1254 (8.9) in the whole soft tissues. Station I is located near one of the largest recreational vessel repainting and repair yards in Newport Harbor. In view of the fact that recreational vessel use and maintenance is the only major anthropogenic activity in Newport Harbor, it appears (as suggested by the San Diego results) that vessel-related activities have led to distinct contamination of harbor organisms by copper and polychlorinated biphenyls.

The data presented in Table B-6c also shows enhanced body burden for several other trace metals. As was the case for copper, contamination factors (Station I/Station H) for zinc in the four mussel tissues were remarkably similar (3.0, 4.1, 2.7, and 2.8). One possible source of this metal is the use of sacrificial zinc anodes to reduce corrosion of immersed metal parts; another is the use of zinc compounds such as zinc chromates in vessel paints (SCCWRP, 1973). Indeed, gonadal tissue of the Station I mussels exhibited a 7-fold increase in chromium concentration, and this tissue also had the highest contamination factors for two other important vessel paint metals, tin (> 18) and lead (> 13). Finally, as we saw in the San Diego Harbor survey, cadmium had distinctly higher concentrations in specimens from the harbor interior. Thus, of the eight metals analyzed, only for silver and nickel was there no demonstrable uptake at harbor Station I over coastal Station H.

Sediments from the vicinity of the Station I intertidal collections also have been found to be highly contaminated with certain metals used in vessel maintenance (Newport Beach, 1972). For example, samples collected in 1971 yielded concentrations of 710, 410, and 12 mg/dry kg for copper, zinc, and mercury, respectively. Corresponding estimates for natural nearshore concentrations in southern California are 16, 63, and 0.04 mg/dry kg (SCCWRP, 1973).

In contrast to the results obtained from the San Diego and Newport Harbor surveys, only slight metals contamination of M. edulis from San Pedro Harbor was observed. Again, the most distinct local effects were seen for copper; the average of four Harbor stations (mean ± S.E.) concentrations was 30 ± 2.3 mg/dry kg, approximately 50 percent above the estimated coastal baseline of about 20 mg/dry kg. Data for copper in the other tissue classes, and for all the other metals in the Harbor specimens, were too variable to suggest any distinct patterns. The fact that the Harbor has three entrances and a very broad and porous breakwater suggest that a much higher flushing rate may be the cause of the relatively low metals contamination factors found in mussels there.

However, one station sampled in this region did reveal elevated metals concentrations in certain tissues of M. edulis. This site was Royal Palms Beach, located directly inshore of the JWPCP submarine discharge of municipal wastewater. From previous studies we have found the JWPCP to be the single largest anthropogenic source of trace metals to the Southern California Bight (Young et al. 1973). The results listed in Table B-6d indicate elevated concentrations of seven of the eight metals in one or more of the Royal Palms mussel tissues analyzed; only in the case of zinc were there no detectable enhancements. The highest contamination factors generally occurred for silver, chromium, and copper. The values for silver in digestive gland, gonad, and "remainder" tissues (excluding muscle) exceeded 4.0, 3.7, and 8.2 respectively. Corresponding values for copper were 2.4, 4.2, and 3.4; for chromium 3.1, 2.2, and 1.7. These were the three metals which we previously had found to have the greatest concentration elevations in digestive glands of the coastal mussel M. californianus collected inshore of the two major Los Angeles municipal outfall systems (Alexander and Young, 1976).

Two other metals, lead and tin, also were more concentrated in the gonadal tissue of the Royal Palms M. edulis specimens, exhibiting contamination factors of >2.9 and >8.5, respectively. These results are similar to those observed in the Newport Harbor survey, where the back-harbor (Station I) specimens apparently concentrated lead and tin in their gonads by factors exceeding 13 and 18, respectively.

5. 1975-76 Benthic Organism Mercury Studies

5.1. Materials and Methods

Between June 1975 and January 1976, six species of benthic animals representing four phyla (a flatfish--the Dover sole, a crab, a prawn, a snail, a sea slug, and a sea urchin) were obtained by otter trawl at depths of 8 m, 60 m, and 140 m off Palos Verdes Peninsula and 80 m, 90 m, 140 m, 150 m, and 180 m off Santa Catalina Island (Figure 2). All animals were rinsed with fresh seawater and frozen in polyethylene bags until target tissues were dissected and analyzed for total and organic mercury by cold vapor atomic absorption spectroscopy.

5.2. Results

Table 7 summarizes concentrations of total and organic mercury in the six different kinds of benthic organisms trawled from the highly-contaminated bottom sediments in the JWPCP outfall monitoring zone off Palos Verdes Peninsula. The distributions of these two types of mercury as a function of trawl station location (Figure 2) in muscle, liver, kidney, and gill tissue of Dover sole, and in whole body samples of the sea slug and muscle tissue of the ridgeback prawn, are illustrated in Figures 6a and 6b. Table 8 presents median* values and ranges of concentrations for total mercury in various tissues of five of the six organisms studied which were available from both the JWPCP and Santa Catalina Island Control areas.

5.3. Discussion

The data on mean mercury concentrations in the six benthic species trawled from around the JWPCP outfalls off Palos Verdes Peninsula (Table 7) indicate that in no case was the U. S. Food and Drug Administration 0.5 mg/wet kg guideline for edible seafood exceeded. While muscle tissue for most of the species tested showed high percentages of organic mercury, the mean levels were below 0.05 mg/wet kg.

The mean value of 0.041 mg/wet kg (organic mercury) observed for Dover sole muscle fell within the range of values for methylmercury found by Zitko et al. (1971) in marine fish from Nova Scotia Banks. Similarly, the mean level of total mercury in Dover sole muscle was statistically indistinguishable from data presented by Childs and Gaffke (1973) for Dover sole caught off the Oregon coast (0.122 ± 0.076 mg/wet kg). De Goeij, et al. (1974) found the livers of Dover sole collected during 1971-72 from the Palos Verdes shelf to contain 0.11 to 0.19 mg/wet kg total mercury, in good agreement with the value of 0.12 mg/wet kg reported here. Apparently, then, Dover sole from the Palos Verdes area contain similar levels of mercury in

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* Used here because of highly skewed Santa Catalina Island values.

Table 7. Levels of total and organic mercury in tissues of benthic marine animals collected from the JWPCP outfall monitoring zone, 1975.

Species and Tissue	No. of Specimens	Total Mercury (mg/wet kg) Mean	Std. Error	Range	Organic Mercury (mg/wet kg) Mean	Std. Error	Range	Average Percent Organic Mercury
Dover sole, Microstomus pacificus								
Muscle	16	0.057	0.006	0.021-0.122	0.041	0.007	0.020-0.103	70.8±5.2
Liver	16	0.124	0.018	0.050-0.296	0.009*	0.002	0.002-0.018	9.6±1.7
Kidney	16	0.053	0.007	0.034-0.125	NA**	NA	NA	NA
Gills	16	0.024	0.003	0.006-0.047	0.010	0.002	0.003-0.023	31.4±7.8
Crab, Mursia gaudichaudii								
Muscle	11	0.021	0.003	0.008-0.037	0.017	0.003	0.014-0.022	87.1±6.8
Digestive gland	11	0.030	0.003	0.011-0.042	0.005	0.001	0.001-0.010	16.0±2.9
Prawn, Sicyonia ingentis								
Muscle	24	0.038	0.002	0.017-0.057	0.029	0.002	0.010-0.043	70.0±4.1
Snail, Callinaticina oldroydi								
Foot	8	0.005	0.002	0.002-0.012	NA	NA	NA	NA
Viscera	8	0.071	0.014	0.026-0.124	0.016	0.007	0.003-0.043	35.9±20.2
Urchin, Allocentrotus fragilis								
Gonad	3	0.021	0.001	0.020-0.024	0.003	NA	NA	15.8
Sea slug, Pleurobranchaea californica								
Whole body	23	0.015	0.002	0.002-0.030	0.007	0.001	0.003-0.017	49.6±5.1

* Only six liver samples were large enough to show detectable quantities of organic mercury.

** Not analyzed or insufficient data.

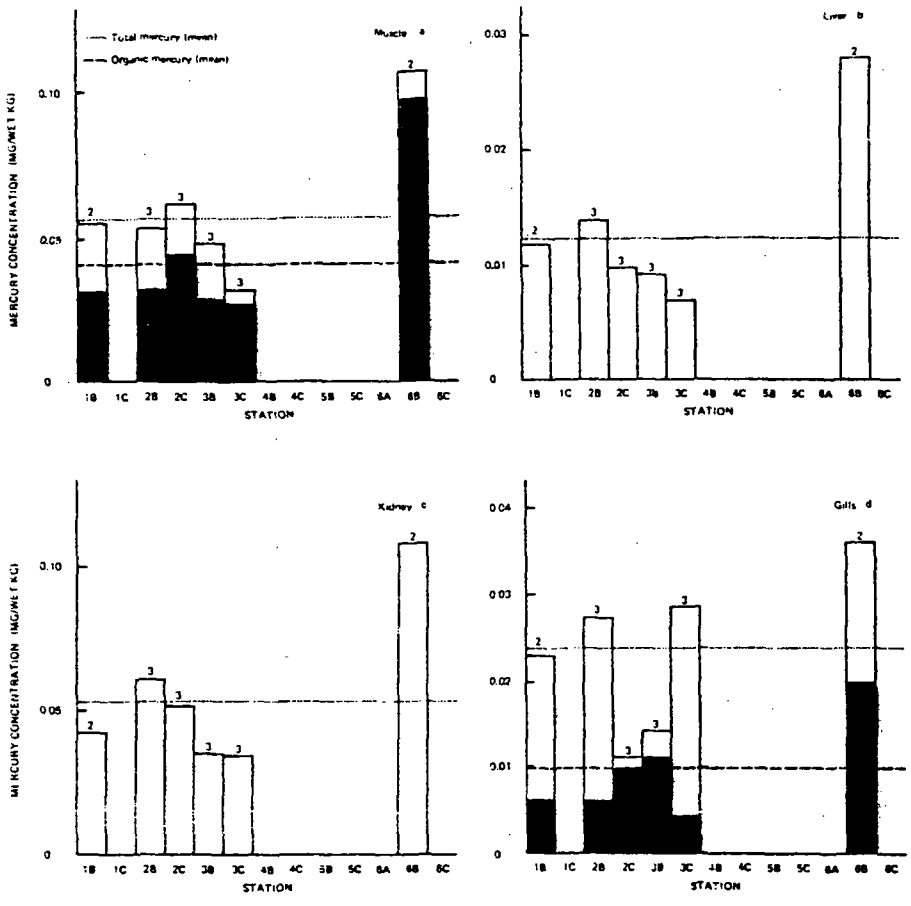

Figure 6a. Mean total (unshaded) and organic (shaded) mercury content (mg/wet kg) in Palos Verdes Dover sole.
(See Figure 2 for station locations.)

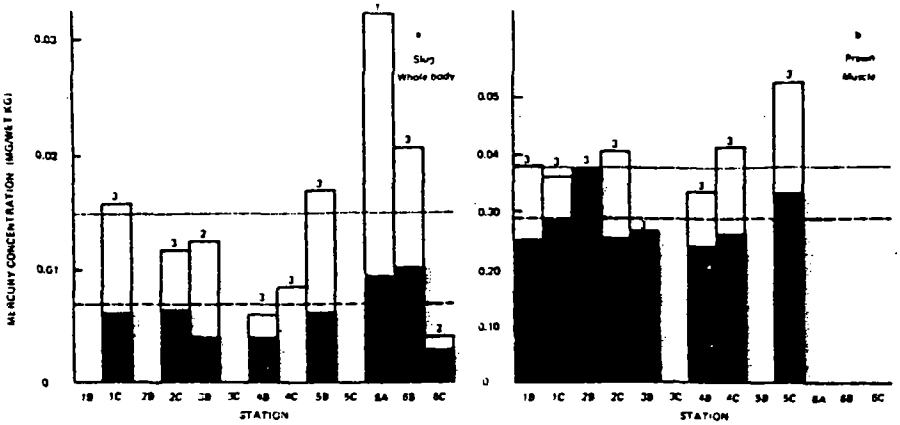

Figure 6b. Mean total (unshaded) and organic (shaded) mercury content (mg/wet kg) in Palos Verdes sea slug and ridgeback prawn. (See Figure 2 for station locations.)

their tissues when compared to fish caught in other coastal regions. These data also indicate that liver mercury concentrations for the 1975 specimens were essentially the same as those measured in 1971-72 specimens by De Goeij, et al. (1974).

In view of the order-of-magnitude difference in total mercury concentrations of surficial sediments that exists between the transects (Figure 6a) nearest and farthest from the JWPCP outfalls (Eganhouse et al. 1976), it was of particular interest to know what, if any, effect sample location might have on the levels of mercury in benthic animals around the outfalls. As Figures 6a and 6b illustrate, tissue concentrations fluctuated randomly about the mean values showing no systematic trend related to sampling locations.

Overall, these results indicate that, in spite of the marked contamination of sediments in which the animals live, tissue concentrations of total and organic mercury in benthic outfall organisms are low, and levels in Dover sole from this area are similar to those found in fishes from other parts of the world.

With the exception of the gills, tissues of the Dover sole showed high inter-tissue correlations with respect to total mercury (Table 9). Correlations between total mercury and organic mercury for various tissues of Dover sole also yielded high coefficients in some cases (Table 10). Significant correlations between tissue concentrations of mercury (total and organic) in Dover sole and body length and weight were observed also (Table 11). The coefficients for muscle were slightly higher than those found by Rivers, et al. (1972). Total mercury shows a consistent distribution among the three tissues (Table 9); however, the diverse correlations between total and organic mercury (Table 10) probably result from dissimilar behavior of the various forms of mercury.

As shown by the results listed in Table 8, in only three of nine cases did the median total mercury levels in tissues of Palos Verdes specimens exceed those found for the Santa Catalina Island control organisms: Dover sole kidneys and gills, and the sea slug. Thus, instead of showing enhanced uptake and accumulation, the outfall organisms tested generally had similar, and sometimes apparently depressed, tissue concentrations of mercury when compared to control specimens. Similar to the findings of De Goeij, et al. (1974), these results suggest that there is no direct relation between the bulk sediment concentrations of mercury and levels found in tissues of the indigenous epifauna. This may be explained by recent findings in this laboratory that mercury in Palos Verdes sediments is largely refractory (unpublished results). Hence, the transfer of mercury from these sediments to benthic organisms appears to be effectively prevented by fixation of mercury in the nondegradable fraction of the sediments.

Table 8. Total mercury (mg/wet kg) in tissues of five benthic animals from off Palos Verdes Peninsula (June 1975) and Catalina Island (January 1976).

Species & Tissue	Palos Verdes			S. Catalina Island		
	N	Median	Range	N	Median	Range
M. pacificus						
Muscle	16	0.052	.021-.122	8	0.157	.050-3.17
Liver	16	0.099	.050-.296	7	0.141	.078-.329
Kidney	16	0.041	.034-.125	8	0.030	.005-.036
Gills	16	0.024	.006-.047	7	0.019	.007-.027
M. gaudichaudii						
Muscle	11	0.018	.008-.037	6	0.158	.067-.516
Digestive gl.	11	0.033	.011-.042	6	0.081	.070-.282
S. ingentis						
Muscle	24	0.038	.017-.057	11	0.049	.022-.089
A. fragilis						
Gonad	3	0.020	.020-.024	6	0.034	.016-.051
P. californica						
Whole body	9	0.016	.002-.030	4	0.011	.006-.016

Table 9. Correlation coefficients for total mercury in tissues of Dover sole, Palos Verdes.

	Muscle	Liver	Kidney	Gills
Muscle	1	0.88*	0.82*	0.30
Liver	-	1	0.89*	0.40
Kidney	-	-	1	0.37
Gills	-	-	-	1

* $p < 0.01$

Table 10. Correlation of total mercury with organic mercury for Dover sole, Palos Verdes.

Total Mercury	Organic Mercury			
	Muscle	Liver	Kidney	Gills
Muscle	0.86*	0.70*	NA	0.85*
Liver	0.91*	0.51	NA	0.75*
Kidney	0.73*	0.13	NA	0.69*
Gills	0.47	-0.82	NA	0.12

* $p < 0.01$

NA = not analyzed for organic Hg; insufficient sample.

Table 11. Correlation of total and organic mercury in tissues of Palos Verdes Dover sole with body weight and standard length (range in standard lengths was 193mm - 260mm).

	Body Weight	Standard Length
Muscle		
Total mercury	0.55**	0.67*
Organic mercury	0.71*	0.58**
Liver		
Total mercury	0.55**	0.66*
Organic mercury	-0.11	0.26
Kidney		
Total mercury	0.61**	0.63*
Gills		
Total mercury	0.20	0.22
Organic mercury	0.62**	0.64**

* $p < 0.01$

** $p < 0.05$

6. Depuration and Uptake Studies

6.1. Materials and Methods

On December 13, 1976, rock scallops were carefully collected inshore of the JWPCP discharge and brought alive to the Project laboratory for depuration in clean filtered seawater. Additional "time-zero" samples from this collection were placed in plastic bags and frozen. The living scallops were placed in aquaria with a flow-through circulating seawater system which was maintained at 13°C. This water was filtered and passed under an ultraviolet light prior to entering the aquaria. Three samples of the unfed rock scallops were randomly collected after a seven-day depuration period and frozen in plastic bags for subsequent dissection and analysis by atomic absorption spectroscopy.

On January 28, 1976, as part of a program sponsored by the U.S. Environmental Protection Agency, specimens of the coastal mussel M. californianus, 4 to 8 cm in length, were collected from Pt. Sal, a remote coastal area 250 km northwest of Los Angeles. Subsamples were randomly selected and frozen for subsequent dissection and mercury analysis; the bulk of the mussels were transferred alive to nylon bags suspended from a taut-line off Palos Verdes. This buoy system had been designed and previously used successfully to maintain mussels for almost six months at several depths to monitor DDT and PCB contamination of the water column around the outfalls (Young et al. 1976). During the first half of 1976, samples of M. californianus also were obtained from San Clemente Island (an offshore control site) and from Royal Palms Beach at the base of the outfalls for comparison with the Pt. Sal specimens. At two- or four-week intervals between February and July three mussels were collected from each level of the buoy and frozen in plastic bags within a few hours.

After twenty-four weeks, the experiment was terminated and digestive gland, adductor muscle, and gonadal tissues were excised from the frozen mussels. Composite samples from the three specimens were prepared for each tissue; these were then analyzed for total mercury by cold vapor atomic absorption spectroscopy as part of the SCCWRP investigation into the kinetics of mercury contamination of organisms near municipal wastewater outfalls.

6.2. Results

The results obtained by AAS analysis of digestive gland, gonad, and adductor muscle tissue from the rock scallops (transferred alive from the JWPCP study area to flow-through seawater aquaria and maintained there for seven days) are presented in Table 12. Medians and ranges of the three specimen values obtained are given, and are discussed in detail below.

Table 12. Concentrations (mg/wet kg) of seven trace metals measured by AAS in three tissues of rock scallops collected inshore of the JWPCP outfalls and depurated for zero and seven days in the Project's flow-through seawater aquaria.

Metal		Digestive Gland		Gonad		Adductor Muscle	
		T-0	T-7	T-0	T-7	T-0	T-7
Ag	Md	2.0	0.56	0.05	0.05	<0.002	<0.004
	Rg	(0.5 - 2.2)	(0.49 - 0.62)	(0.01 - 0.12)	(<0.002 - 0.06)	(<0.002)	(<0.002 - 0.008)
Cd	Md	760	370	3.4	1.8	0.78	0.79
	Rg	(240 - 1000)	(350 - 520)	(0.48 - 5.6)	(0.69 - 2.0)	(0.54 - 1.3)	(0.64 - 0.95)
Cr	Md	25	27	5.3	6.8	0.18	0.34
	Rg	(11 - 67)	(18 - 32)	(0.8 - 12)	(1.9 - 14)	(0.13 - 0.49)	(0.18 - 0.56)
Cu	Md	207	123	2.3	1.1	0.15	0.08
	Rg	(95 - 220)	(115 -180)	(2.1 - 3.0)	(1.0 - 1.1)	(0.08 - 0.29)	(<0.04 - 0.21)
Ni	Md	0.60	0.31	<0.05	0.03	<0.03	<0.04
	Rg	(0.55 - 0.70)	(0.14 - 0.62)	(<0.02 - 0.13)	(<0.03 - 0.04)	(<0.04)	(<0.05)
Pb	Md	3.7	2.2	<0.05	<0.03	0.06	<0.04
	Rg	(3.0 - 4.5)	(1.6 - 2.5)	(<0.05)	(<0.04)	(<0.04 - 0.19)	(<0.08)
Zn	Md	102	102	36	7.6	19	21
	Rg	(64 - 140)	(78 - 108)	(25 - 41)	(6.7 - 8.2)	(18 - 20)	(19 - 21)

Figure 7 illustrates the rate of uptake of total mercury in adductor muscle, gonadal, and digestive gland tissues of coastal mussels transferred alive from the Pt. Sal control site to the taut-line buoy maintained for twenty-four weeks off the JWPCP outfalls. A comparison of total mercury levels in the tissues of mussels collected from Pt. Sal, San Clemente Island, and Royal Palms Beach is given in Table 13. The Pt. Sal and San Clemente Island data were in good agreement, indicating that the test animals transferred to the buoy were relatively uncontaminated with respect to mercury. By comparison, all three tissues of the Royal Palms mussels contained roughly 2.5 times as much as of this trace metal as the control samples. Previous work has shown that these differences are well outside experimental error (Eganhouse and Young 1976). It should be noted that the values obtained for the Royal Palms specimens were nearly an order of magnitude below the U.S. Food and Drug Administration guideline of 0.5 mg/wet kg.

6.3. Discussion

The results of the seven-day rock scallop depuration experiment presented in Table 12 suggest that depuration does not lead to major changes in metals concentrations in the three tissues of this filter-feeding mollusk. Although the relatively large ranges observed in the triplicate samples makes quantitative comparisons questionable in individual cases, on the average it is seen that the levels in the undepurated specimens are seldom more than twice those measured in the depurated specimens. Only for copper were decreases seen in all three tissues (with uniform decreases by about a factor of 2).

The largest loss occurred in the case of gonadal zinc, where the factor of 5 decrease appears to be statistically significant. Also, the median concentration of digestive gland silver decreased by about a factor of 4 over the seven-day interval.

As one would expect, the digestive gland in general showed the greatest loss of metals over the seven day depuration interval. Decrease factors ($^{T-0}/_{T-7}$) for Ag, Cd, Cr, Cu, Ni, Pb, and Zn in this time were: 3.6, 2.1, 0.9, 1.7, 1.9, 1.7, and 1.0, respectively. For the gonads these factors were: 1.0, 1.9, 0.8, 2.1, N.D., N.D. and 4.7; for adductor muscle: N.D., 1.0, 0.5, 1.9, N.D., $\geq$1.5, and 0.9. Thus, these results suggest that, in general, depuration or lack of it does not appear to have an important effect on levels in the edible muscle tissue.

The results of the mercury uptake studies, in which control mussels were cultured at four depths off the JWPCP outfalls (Figure 7) indicate that the response of the digestive gland was relatively rapid, with mercury concentrations in the buoy specimens exceeding those in the Royal Palms specimens within two to five weeks. At no time during the

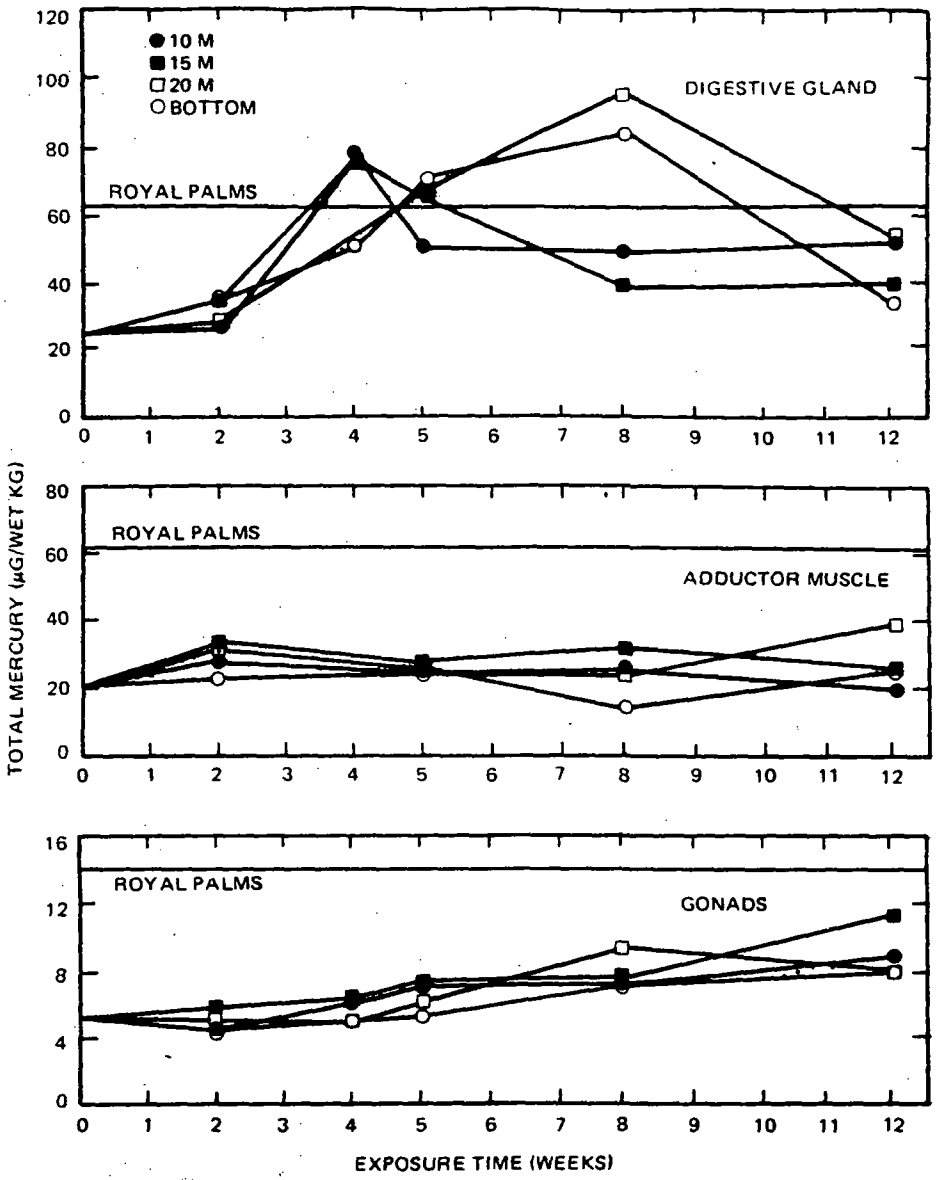

Figure 7. Uptake of total mercury in mussel tissues, M. californianus, verses exposure time at four depths. Mussels were transported from Point Sal and suspended on a buoy off Royal Palms Beach, adjacent to the JWPCP outfall system.

Table 13. Total mercury (µg/wet kg) in tissues of M. californianus from three southern California intertidal stations, 1976.

Station	Digestive gland	Adductor muscle	Gonad
Pt. Sal	26.7	20.6	5.1
	26.4	19.3	4.5
	21.1	28.3	5.8
San Clemente Island	23.0	21.5	6.4
Royal Palms	62.8	61.8	14.2

experiment did the levels return to the initial mean concentration of 24.7 µg/wet kg. Since no distinct pattern was observed with depth, the contaminated bottom sediments around the outfalls did not appear to be acting as a source of mercury to the buoy mussels. To determine whether or not the apparent increases with time in digestive gland mercury content were significant, we subjected the data to statistical analysis. In view of the lack of correlation with depth, we pooled data from the four depths for each exposure time and evaluated them by analysis of variance (Steel and Torrie 1960). The results showed that the observed changes with time were statistically significant ($p<0.05$).

In its role as a primary digestive organ, the digestive gland probably reflected changes in the mercury content of the available suspended particulate matter. Presumably, these changes were caused by fluctuations in the movement of local currents. Under these conditions the buoy specimens could have experienced some variability in their exposure to the wastewater plume during the experiment.

Within the first twelve weeks of the experiment, the levels of mercury in the adductor muscle tissue did not increase substantially. After this period, values for the 10 and 20 meter depths began to approach the Royal Palms value. This trend was not observed for the 15 m and 30 m depths; the values at these depths fluctuated throughout the experiment at levels slightly above the initial concentration. Thus, the adductor muscle is apparently not as responsive as the digestive gland to changes in environmental levels of mercury, exhibiting a rather chronic response pattern instead. Analysis of variance for the pooled exposure time intervals revealed that these concentration changes were not statistically significant ($p>0.05$). From these results, it appears that a minimum exposure period of six months would be required for adductor muscle levels to reach those measured in the Royal Palms mussels.

Gonadal tissues showed a gradual increase in mercury content at all depths over the first twelve weeks of the study. Highest levels were found at either the sixteen- or twenty-week sampling intervals followed by an abrupt decline to values below the Royal Palms concentration. At each depth, the maximum concentration observed closely approached or exceeded the Royal Palms value, suggesting that significant uptake had occurred within the exposure period. Using the analysis of variance, we found these concentration changes to be statistically significant ($p<0.05$).

Dissimilarities in the response patterns found for the three tissues studied may partially be attributed to differences in the physiological functions these tissues perform. Accordingly, the mercury content of the digestive gland probably reflects the levels of ambient detrital mercury while adductor muscle and gonadal tissue concentrations more accurately represent actual incorporation following digestion of

the detritus. The results of this experiment would seem to indicate a very low efficiency of conversion for particulate-associated mercury by tissues such as the adductor muscle and gonads. The absence of any trends with depth argues against the hypothesis that the highly contaminated bottom sediments in this area have acted as a source of mercury to the buoy mussels during the experiment. Likewise, the nonappearance of a strong thermocline during most of this experiment, with resultant mixing of the buoyant wastewater plume, is consistent with a lack of correlation with depth. Results which we have obtained recently from research still in progress suggest that mercury bound in these sediments resembles the effluent particulates being discharged from the outfalls in that it is largely refractory, that is, biologically unavailable. As a consequence, the relatively slow increase in mercury observed for the adductor muscle and gonadal tissues may be due to the difficulty with which particulate-associated mercury is broken down in the digestive tract of the mussel.

Moreover, since accumulation is the net result of uptake and loss processes, the patterns we obtained may also reflect differences in mercury depuration rates of the individual tissues. In this regard, the relatively rapid changes in tissue mercury concentrations found for gonads at all depths near the end of the experiment indicate that depuration may not be as difficult for mollusks under stress conditions as has been observed in laboratory studies (Miettinen et al. 1970; Mellinger 1972; Cunningham and Tripp 1973). The possibility of spawning cannot be ruled out as a cause for the observed results.

CONCLUSIONS

The results of the studies reported here indicate that the edible portion of certain seafood species caught around submarine discharges of municipal wastewater in southern California can be contaminated by a number of trace metals. However, these tissue concentrations are quite low, generally near or below a part-per-million. The only metal for which there is an accepted public health standard is mercury, and in no case did the median value in an edible tissue exceed the U.S. Food and Drug Administration action level of 0.5 mg/wet kg.

No clear elevations above normal levels were found for any of the target metals in muscle of fishes collected near the wastewater outfalls. A number of the outfall invertebrates studied did contain distinct elevations of various metals above control values. Most of the measurable contamination factors were less than 4; however, scallops and abalone collected around the Los Angeles County JWPCP outfall system contained up to 10 times control chromium levels in their muscle tissue. Laboratory depuration studies with contaminated scallops from this zone did not yield significant reductions in muscle tissue concentrations of metals over a one-week period.

The coastal region which exhibited the highest metals concentrations was the JWPCP discharge off the Palos Verdes Peninsula. However, similar contamination factors were measured in intertidal mussels from vessel anchorages and repair yards in Newport and San Diego Harbors. Thus, it appears that both submarine discharges of municipal wastewater and harbor-based vessel activities can lead to distinct contamination of marine invertebrates by a variety of trace metals. The physiological, ecological, and public health significance of these elevated tissue burdens should be determined.

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SAMPLE PREPARATION

Dissection of the semi-thawed organisms was performed in a clean glass enclosure to minimize contamination, and on acid cleaned plastic sheets using scalpels with carbon steel blades. Plastic tipped forceps were used to cleanly excise the semi-frozen tissues which were placed in pre-weighed plastic vials pending freeze-drying for analysis by optical emission spectroscopy, or acid digestion for analysis by atomic absorption. Additional segments of selected tissues were placed in kiln-fired glass jars for subsequent analysis of elemental mercury by cold vapor atomic absorption spectroscopy. Care was taken to prevent contamination of the tissue samples by the dissector (who wore plastic gloves and frequently cleaned his instruments with 6% HNO_3 and deionized water), or cross-contamination of one organ by fluids from another during dissection.

1. Optical Emission Spectroscopy

Over the past decade, a specialized optical emission spectrometer system has been developed by one of the co-authors (G. Alexander) at the Laboratory of Nuclear Medicine (University of California at Los Angeles) to determine the levels of stable elements present in dry biological tissue. The heart of the system is an optical emission spectrometer covering the wavelength range of 210 nm to 670 nm and having a reciprocal linear dispersion of 0.68 nm/mm. Forty-four detector units are arranged on the focal circle of this instrument. Each detector is comprised of a secondary slit, a mirror to focus this slit image on the cathode of a photomultiplier tube, and an interference filter to eliminate unwanted scattered light originating from the grating of the spectrometer.

In order to carry out the analysis, the sample must be volatilized, the resulting molecules disassociated into atoms, and these atoms exited by means of an electrical discharge to give off the characteristic optical spectra for the elements present within the tissue. To accomplish this, a crater electrode with a 1.9 mm diameter stem is used. Five to 15 mg of freeze-dried sample are weighed into the crater. No additional materials are added to the sample. A 12.5 ampere D.C. arc is drawn between the electrodes to volatilize the sample and excite the elements. During this process, each detector charges a capacitor at a rate proportional to the intensity of the light received. Thus, when the sample has been consumed, each capacitor is charged to a voltage proportional to the total intensity received by the detector. By relatively simple calculations, the electrode background can be subtracted from each signal and a net intensity derived.

By suitable standardization, these net intensities can be converted into concentrations. In this system, the total intensities are automatically transferred to IBM cards and then processed by means of an IBM 360-91 computer to concentrations. The spectral lines which are used for the analysis are shown in Table A-1. The relative standard deviation of analysis is generally between 3% and 15% for finely ground material. The accuracy of analysis is largely dependent upon the adequacy of the calibration standards, but as judged by comparison with the NBS Standard Reference Materials (Table A-2), is quite good at levels above 1 mg/dry kg.

The important features of this method, beyond its simultaneous multi-element capacity, are that each analysis is performed at a materials cost of less than 50¢ and, on the average, no more than five minutes of technician time, including sample preparation and analysis, is required (Alexander et al. 1975).

Table A-1. Analytic line array used in OES analyses (from Alexander et al. 1977)

ANALYTICAL LINES

P	2535.6	Mn	2576.1	Ba	4934.1
Na	3302.3	Mn	2933.1	Li	6103.6
Na	6154.2	B	2497.7	Ag	3280.7
K	4044.1	Al	3082.2	Sn	2840.0
Ca	3158.9	Si	2881.6	Pb	2833.1
Ca	4454.5	Ti	3372.8	Be	2348.6
Mg	5183.6	V	4379.2	Be	3131.1
Zn	2138.6	Ni	3414.8	Cd	2288.0
Zn	3282.3	Mo	3132.6	Hg	2536.5
Cu	3247.5	Cr	4254.4	As	2780.2
Fe	2488.2	Sr	4077.7	Sb	2598.1

BACKGROUND POSITIONS

CN	3383.4	Bkgd 2	5219.6	SiO	2413.8
TL	4001.0	Bkgd 3	2204.0	CaO	6193.5
C_2	4714.8	Bkgd 4	2104.0	PO	2462.7

Table A-2. Comparison of results for Standard Reference Materials No. 1577 (Bovine Liver) and No. 1571 (Orchard Leaves) reported by the U.S. National Bureau of Standards with those obtained by OES at the Laboratory of Nuclear Medicine and Radiation Biology (from Alexander et al. 1977)

ANALYSIS SRM #1577

ELEMENT	NBS	NMRB
K	0.97 ± 0.06%	0.98 ± 0.17%
Na	0.243 ± 0.013%	0.252 ± 0.096%
Fe	270 ± 20ppm	276 ± 88ppm
Cu	193 ± 10	190 ± 59
Zn	130 ± 10	127 ± 27
Mn	10.3 ± 1.0	10.7 ± 2.5
Pb	0.34 ± 0.08	0.18± 0.34
Cd	0.27 ± 0.04	1.8 ± 1.2
	250 mg Aliquotes	10 mg Aliquotes

ANALYSIS OF SRM #1571

ELEMENT	NBS	NMRB
Ca	2.09 ± 0.03%	2.31 ± 0.27%
K	1.47 ± 0.03%	1.36 ± 0.03%
Mg	0.62 ± 0.02%	0.64 ± 0.06%
P	0.21 ± 0.01%	0.21 ± 0.04%
Fe	300 ± 20ppm	281 ± 67ppm
Mn	91 ± 4	90 ± 11
Na	82 ± 6	80 ± 20
Pb	45 ± 3	43 ± 9
B	33 ± 3	33 ± 5
Zn	25 ± 3	25 ± 8
Cu	12 ± 1	11 ± 2
Ni	1.3 ± 0.2	1.0 ± 0.3
Cd	0.11 ± 0.02	0.7 ± 0.8
	250 mg Aliquotes	10 mg Aliquotes

2. Atomic Absorption Spectroscopy

At the Southern California Coastal Water Research Project Laboratory, biological samples are digested in the wet state and then analyzed for trace metals utilizing a Varian Techtron AA6 atomic absorption spectrometer. First, 1-3 wet grams of each tissue sample is digested in 10 ml of a 1:1 nitric acid solution (ultrahigh-purity reagent grade) until the remaining volume is about 3 ml. This procedure is repeated once, and the final residue is filtered through an acid-washed Whatman No. 40 filter. The filtrate is then diluted to an appropriate volume for analysis. Silver, cadmium, chromium, copper, nickel, and lead are measured by injecting 2.5 µl of sample into the graphite furnace of the AA6. Zinc levels are determined by aspirating the sample into an air-acetylene flame. Process blanks are analyzed with each set of samples. The concentrations of target trace metals are determined from corresponding standard curves. The experimental conditions of the spectrophotometer are given in Table A-3. Our AAS results for Standard Reference Material No. 1571 (Orchard Leaves) are shown in Table A-4 to be in good agreement with those reported by the U.S. National Bureau of Standards.

3. Cold Vapor Atomic Absorption Spectrometry

a. Total Mercury. Up to 10 g of tissue are homogenized as a 50/50 mixture with distilled water in a homogenizer. Using a medicine dropper or spatula, 0.2 to 1.0 g of homogenate is transferred to a 250-ml flat-bottomed boiling flask. Twenty ml of a 3:1 H_2SO_4/HNO_3 solution are added to the flasks, which are then attached to a hotplate condenser apparatus. The samples are digested at 200°C for 15 to 20 minutes and cooled to room temperature. A pale yellow to colorless solution should result. The flasks are then detached from the rinsed condensers and are reheated (in a fume hood) at 200°C until all NO_x gases have been released. This usually takes from 15 to 30 minutes. The samples are then cooled to room temperature and analyzed as follows.

A teflon-coated stirring bar and 145 ml of distilled water are added to the flask, which is then attached to a purge system. After 5.0 ml of the stannous chloride solution have been injected into the flask, the magnetic stirrer is turned on for 60 seconds, and the N_2 flow is started. Elemental mercury is carried by the nitrogen through the sample cell, and the absorbance at the 254-nm wavelength is displayed on a strip chart recorder in the form of a peak. The amount of mercury in the sample is determined by comparing the integrated peak area to a standard curve. In our work, peak area has been found to be a more precise measure of the mercury present than peak height. For each day's run, a standard curve is constructed from data obtained

Table A-3. Experimental conditions for AAS analyses.

General Instrument Parameters:

Element	Wave Length nm	Lamp Current mA	S.B.P. nm
Ag	328.1	3	0.5
Cd	228.8	3	0.5
Cr	357.9	5	0.2
Cu	324.7	3	0.5
Ni	232.0	5	0.2
Pb	217.0	5	1.0
Zn	213.9	5	0.5

Atomizer Settings:

		Voltage (mA)	Time (second)
Dry		2-3	50
Ash		4.5-6.0	20
Atomize	Ag	6.5	2
	Cd	7.0	2
	Cu	7.0	2
	Cr	7.0	2
	Ni	7.5	2
	Pb	6.0	2

Flame Conditions:

	Supply Pressure	Flow Meter
Air	50 psi	3.0
Acetylene	10 psi	2.0

Table A-4. Comparison of results (mg/dry kg) for Standard Reference Material No. 1571 (Orchard Leaves) reported by the U.S. National Bureau of Standards with those obtained by AAS at the SCCWRP laboratory.

Element	NBS	SCCWRP
Ag	-	<0.01
Cd	0.11 ± 0.01	0.14
Cr	2.6 ± 0.3	2.5
Cu	12 ± 1	10
Mn	91 ± 4	82
Ni	1.3 ± 0.2	0.94
Pb	45 ± 3	38
Zn	25 ± 3	27

for five processed standard samples ranging from 25 to 500 ng of mercury as mercuric chloride ($HgCl_2$). A blank is also run. The standards are prepared daily using a concentrated stock solution (at about 100 mg/l) by serial dilution. One ml of concentrated HNO_3 is added for every 100 ml of standard solution to minimize loss of mercury by adsorption or vaporization. The 100 mg/l stock solution can be used effectively for one week.

b. Organic Mercury. Up to 10 g of tissue are homogenized as a 50/50 mixture with distilled water using a homogenizer. Five to 10 g of the homogenate are immediately weighed into a 250 ml centrifuge bottle (with teflon-lined cap), and 10 g NaCl, 70 ml of distilled water, and 15 ml of concentrated HCl are added. The mixture is shaken to dissolve the salt; then 65 ml of benzene is placed in the bottle, and the mixture is shaken on a wrist-action shaker for at least 10 minutes. The contents are then centrifuged at 1,200 rpm for 20 minutes or until the benzene layer is clear. A pipette is used to transfer 50 ml of the benzene extract to a 60-ml separatory funnel. Seven ml of a cysteine solution (1.0 g cysteine HCl, 0.744 g Na acetate, 12.0 g Na_2SO_4, and 100 ml water) is added to the funnel, and the mixture is shaken for 3 minutes. Once the phases have separated (centrifugation may be necessary), the cysteine extract is drained into a test tube. The extracts may be stored for at least 10 days in sealed test tubes or centrifuge tubes. Two ml of the cysteine extract solution are transferred by pipette to a 250-ml flat-bottomed boiling flask. After 20 ml of aqua regia have been added to the flask, the contents are digested (as previously described) for 1 hour at a setting of 3.5 (135°C). The flasks are cooled, condensers rinsed, and samples analyzed in the same manner described for total mercury. The standards are made up with distilled water using a stock solution at 100 mg/l MeHgCl. The dilute standards must be prepared daily, but the stock solution is usable for three to four days. Additional details of analysis are discussed by Eganhouse (1975).

APPENDIX B

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TABLE B-1. Collection methods by species.

GROUP	ORGANISM	GENUS SPECIES	BOTTOM TRAWL	HOOK AND LINE	TRAP	SPEAR	HAND
A	Black Abalone	*Haliotis cracherodii*					X
	Ca. Spiny Lobster	*Panulirus interruptus*			X		
	Bocaccio	*Sebastes paucispinis*	X	X			
	Ca. Halibut	*Paralichthys californicus*	X	X			
	Ca. Scorpion Fish	*Scorpaena guttata*	X	X			
	Kelpbass	*Paralabrax clathratus*		X		X	
	White Croaker	*Genyonemus lineatus*	X	X			
B	Red Sea Urchin	*Strongylocentrotus franciscanus*					X
	Ridgeback Prawn	*Sicyonia ingentis*	X				
	White Squid	*Loligo opalescens*	X				X
	Yellow Crab	*Cancer anthonyi*	X		X		X
	Barred Sandbass	*Paralabrax nebulifer*				X	
	Northern Anchovy	*Engraulis mordax*	X				
	Pacific Bonito	*Sarda chiliensis*		X			

TABLE B-1. Collection methods by species. (Continued)

GROUP	ORGANISM	GENUS SPECIES	BOTTOM TRAWL	HOOK AND LINE	TRAP	SPEAR	HAND
B (continued)							
	Pacific Sanddab	*Citharichthys sordidus*	X	X			
C	Rock scallop	*Hinnites giganteus*					X
	Intertidal Mussel	*Mytilus californianus*					X
	Bay Mussel	*Mytilus edulus*					X
OTHERS							
	Dover sole	*Microstomus pacificus*	X				
	Red Pointer crab	*Mursia gaudichaudii*	X				
	Snail	*Callinaticina oldroydi*	X				
	Fragile urchin	*Allocentrotus fragilis*	X				
	Sea slug	*Pleurobranchaea californica*	X				

Table B-2. Comparison of results (mg/dry kg) obtained by OES and AAS on split samples of muscle, gonad, and liver tissue from five seafood fishes, collected 1975-76.

Fish and Region	Sample Number	MUSCLE OES/AAS and Ratio Ag	Cd	Cr	Cu	Ni	Pb	Zn
White Croaker -OCSD-	1	0.3/0.05 6.00	<2.9/<0.01 -	0.2/0.43 0.47	1.2/1.20 1.00	<1.9/1.39 -	<1.0/1.14 -	11.9/11.7 1.02
	2	0.3/0.05 6.00	<2.8/<0.01 -	<0.2/0.09 -	2.2/1.50 1.47	<1.9/0.58 -	<0.9/0.90 -	9.1/12.5 0.73
Scorpion-fish Santa Catalina Isl.	1	0.2/0.06 3.33	<3.0/0.21 -	<0.2/0.07 -	0.5/0.36 1.39	<2.0/0.27 -	<1.0/1.27 -	10.2/13.8 0.74
	2	0.3/0.05 6.00	<2.9/0.16 -	<0.2/0.05 -	2.2/0.90 2.44	<2.0/<0.93 -	<1.0/0.24 -	16.1/19.4 0.83
California Halibut -OCSD-	1	0.3/0.08 3.75	<2.9/0.03 -	<0.2/0.03 -	0.6/0.44 1.36	<1.9/<0.11 -	<1.0/<0.03 -	10.0/10.2 0.98
	2	0.3/0.07 4.29	<3.1/0.02 -	<0.2/0.04 -	0.3/0.53 0.57	<2.1/1.07 -	<1.0/1.07 -	11.0/10.3 1.07
Bocaccio -JWPCP-	1	0.3/0.02 15.00	<2.8/0.01 -	<0.2/0.03 -	1.5/1.04 1.44	<1.9/<0.08 -	<0.9/<0.03 -	12.1/14.3 0.85
	2	0.4/0.07 5.71	<3.0/0.04 -	<0.2/0.07 -	0.6/0.75 0.80	<2.0/<0.11 -	<1.0/0.23 -	11.7/16.6 0.70
Kelp Bass -JWPCP-	1	0.3/0.02 15.00	<3.0/<0.01 -	<0.2/0.14 -	0.4/0.49 0.82	<2.0/0.11 -	<1.0/0.39 -	9.5/12.4 0.77
	2	0.4/0.05 8.00	<3.0/0.01 -	<0.2/0.09 -	0.5/0.44 1.14	<2.0/0.14 -	<1.0/0.85 -	10.6/11.8 0.90

Table B-2. Cont.

Fish and Region	Sample Number	GONAD OES/AAS and Ratio Ag	Cd	Cr	Cu	Ni	Pb	Zn
White Croaker -OCSD-	1	0.5/0.10 5.00	<3.2/0.68 -	<0.2/0.41 -	2.5/2.01 1.24	<2.2/1.57 -	<1.1/2.9 -	62/66 0.94
	2	0.7/0.10 7.00	3.9/2.10 1.86	<0.2/0.14 -	7.2/6.56 1.10	<2.1/0.39 -	<1.1/0.18 -	394/539 0.73
Scorpion-fish Santa Catalina Isl.	1	0.6/0.18 3.33	<3.3/0.70 -	<0.2/0.82 -	2.2/1.35 1.63	<2.2/2.5 -	<1.1/3.63 -	35/46 0.76
	2	0.5/0.50 1.00	<3.2/4.74 -	<0.2/0.15 -	15.2/13.4 1.14	<2.1/1.00 -	<1.1/<0.18 -	95/119 0.80
California Halibut -OCSD-	1	0.5/0.41 1.22	<2.8/0.04 -	<0.19/0.08 -	3.6/4.15 0.87	<2.0/0.41 -	<0.9/<0.06 -	52/58 0.90
	2	0.6/0.29 2.07	<3.3/0.41 -	<0.2/0.19 -	9.2/6.43 1.43	<2.2/0.48 -	<1.1/<0.12 -	78/65 1.20
Bocaccio -JWPCP-	1	0.4/0.17 2.35	<3.0/0.03 -	<0.2/0.06 -	12.7/9.18 1.38	<2.0/0.34 -	<1.0/<0.07 -	252/373 0.68
	2	0.4/0.39 1.03	<3.0/0.74 -	<0.2/0.32 -	2.8/3.6 0.78	<2.0/0.38 -	<1.0/0.16 -	36/62 0.58
Kelp Bass -JWPCP-	1	0.6/0.03 20.00	<?.8/0.39 -	<0.2/0.13 -	1.3/2.14 0.61	<1.9/0.33 -	<0.9/<0.13 -	468/583 0.80
	2	0.6/0.16 3.75	<3.3/0.28 -	<0.2/0.17 -	2.1/2.64 0.80	<2.2/0.37 -	<1.1/0.25 -	292/554 0.53

Table B-2. Cont.

Fish and Region	Sample Number	LIVER OES/AAS and Ratio Ag	Cd	Cr	Cu	Ni	Pb	Zn
White Croaker -OCSD-	1	1.6/0.86 1.86	<2.9/11.8 -	<0.2/0.28 -	26.3/21.8 1.21	<2.0/<0.51 -	<1.0/0.64 -	44.7/104 0.43
	2	1.1/0.62 1.77	3.4/11.4 0.30	<0.2/0.33 -	13.7/17.3 0.79	<1.8/0.39 -	<0.9/0.27 -	52.1/105 0.50
Scorpion-fish Santa Catalina Isl.	1	0.4/0.11 3.64	<2.9/0.74 -	<0.2/0.08 -	4.5/5.43 0.83	<1.9/<0.36 -	<1.0/<0.24 -	22.7/63.3 0.36
	2	0.4/0.27 1.48	<3.0/3.47 -	<0.2/0.13 -	15.3/13.3 1.15	<2.0/0.24 -	<1.0/0.53 -	43.3/130 0.33
California Halibut -OCSD-	1	0.7/0.27 2.59	<2.8/1.79 -	<0.2/0.10 -	61.3/42.8 1.43	<1.9/<0.30 -	<0.9/0.06 -	106/225 0.47
	2	0.6/0.21 2.86	<3.3/1.53 -	<0.2/0.09 -	52.0/35.2 1.48	<2.2/0.27 -	<1.1/0.27 -	70.4/264 0.27
Bocaccio -JWPCP-	1	0.3/0.05 6.00	<3.0/0.48 -	<0.2/0.06 -	12.5/9.23 1.35	<2.0/0.31 -	<1.0/0.23 -	53.3/87.4 0.61
	2	0.4/0.05 8.00	<2.9/0.30 -	<0.2/0.15 -	5.8/6.48 0.90	<2.0/<0.33 -	<1.0/<0.16 -	30.8/63.8 0.48
Kelp Bass -JWPCP-	1	0.3/0.06 5.00	7.8/22.8 0.34	<0.2/0.13 -	3.5/4.34 0.81	<2.1/0.73 -	<1.0/<0.23 -	47.4/72.8 0.65
	2	0.2/0.02 10.00	<3.0/3.67 -	<0.2/0.08 -	4.1/3.14 1.31	<2.0/<0.36 -	<1.0/<0.18 -	39.7/45.1 0.88

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Table B-3. Mean dry weight to wet weight ratio x 100, as a function of organism, tissue, and collection region.

SPECIES	MUSCLE				GONAD				LIVER				KIDNEY				SKIN			
	LA	OC	CC	IC	LA	OC	CC	IC	LA	OC	CC	IC	LA	OC	CC	IC	LA	OC	CC	IC
Group A																				
Black Abalone*	25		24	28					27		24	31								
Ca. Spiny Lobster*	26		26	23	38		44	37	36		41	27	16		22	29				
Bocaccio	28			20	30			35	39			27	31			20	42			32
Ca. Halibut	24	25	24		21	21			37			45	21	22			26	34		
Ca. Scorpionfish	23	24	21	25	20	24	36	24	48	55	34	47	22	22	19	21	31	31	32	37
Kelp Bass	24	25		23	27	25		26	39	36		31	26	22		23	45	41		43
White Croaker	22	23	19		20	19	18		29	39	23		20	17	17		54	48	33	
Group B																				
Red Sea Urchin					30		24	19												
Ridgeback Prawn		26	25	23																
White Squid	20			20																
Yellow Crab	20	23	27																	
Barred Sandbass		27																		
Northern Anchovy	30	25	25	24																
Pacific Bonito	28	25	31																	
Pacific Sanddab	21		18																	
Group C																				
Rock Scallop	24																			

LA = J.W.P.C.P.
OC = O.C.S.D.
CC = Coastal Control
IC = Island Control

* Abalone Liver = Digestive gland and gonadal tissues
Lobster Liver = Digestive gland
Lobster Kidney = Green gland
Intertidal mussel liver = Digestive gland

Table B-4a. Median Concentrations (mg/wet kg) and ranges (n=3) of seven trace metals measured by AAS in edible tissue of seafood organisms collected from two outfall and two control regions during 1975-76.

SILVER

ORGANISM	JWPCP	OCSD	COASTAL CONTROL	ISLAND CONTROL
Red Sea Urchin	<0.01(< 0.01-0.01)			<0.01(<0.01)**
Black Abalone	0.03(< 0.01-0.06)			<0.01(<0.01-0.02)
Ridgeback Prawn	<0.01(<0.01)	0.02(<0.01-0.05)	<0.01(<0.01-0.01)	
Yellow Crab	0.10(0.09-0.19)		0.22(0.08-0.29)	
Spiny Lobster	0.05(<0.01-0.06)		0.02(<0.01-0.03)	0.01(0.01-0.02)
White Croaker	0.02(0.02-0.03)	0.03(0.02-0.03)	0.02(0.02-0.06)	
Pacific Sanddab	<0.01(<0.01-0.01)	<0.01(<0.01)	<0.01(<0.01-0.01)	<0.01(<0.01)
Ca.Scorpionfish	0.02(0.01-0.02)	0.02(0.02-0.04)	0.02(0.02-0.03)	
Calif. Halibut	<0.01(<0.01)**		<0.01(<0.01)**	
Bocaccio	<0.01(<0.01)	<0.01(<0.01)		<0.01(<0.01-0.01)
Kelp Bass		<0.01(<0.01-0.02)		<0.01(<0.01)

* Based on OES analyses

** n = 2

Table B-4a. CONT.

ORGANISM	CADMIUM			
	JWPCP	OCSD	COASTAL CONTROL	ISLAND CONTROL
Red Sea Urchin	0.13(0.04-0.17)			0.44(0.44-0.45)**
Black Abalone	0.04(0.03-0.07)			0.03(0.03)
Ridgeback Prawn	0.03(0.02-0.05)	0.06(0.06-0.08)	0.04(<0.01-0.07)	
Yellow Crab	<0.01(<0.01-0.01)		0.01(0.01)	
Spiny Lobster	0.02(<0.01-0.04)		<0.01(<0.01-0.03)	<0.01(<0.01)
White Croaker	<0.01(<0.01)	<0.01(<0.01)	<0.01(<0.01)	
Pacific Sanddab	<0.01(<0.01)	<0.01(<0.01)	<0.01(<0.01)	<0.01(<0.01)
Ca.Scorpionfish	<0.01(<0.01-0.07)	<0.01(<0.01)	<0.01(<0.01)	
Calif. Halibut	<0.01(<0.01)**		<0.01(<0.01)**	
Bocaccio	<0.01(<0.01)	<0.01(<0.01)		<0.01(<0.01)
Kelp Bass		<0.01(<0.01-0.01)		<0.01(<0.01)

* Based on OES analyses

** n = 2

Table B-4a. Cont.

ORGANISM	CHROMIUM JWPCP	CHROMIUM OCSD	CHROMIUM COASTAL CONTROL	CHROMIUM ISLAND CONTROL
Red Sea Urchin	0.14(0.04-0.16)			0.18(0.16-0.19)**
Black Abalone	1.0 (0.87-2.2)			0.10(0.04-0.10)
Ridgeback Prawn	<0.02(<0.03)	0.12(0.02-0.13)	0.02(0.02)	
Yellow Crab	0.08(0.05-0.09)		0.04(<0.02-0.06)	
Spiny Lobster	0.03(<0.02-0.03)		0.04(0.01-0.10)	<0.02(<0.02-0.04)
White Croaker	0.06(0.06-0.07)	0.06(0.06-0.07)		0.02(<0.02-0.03)
Pacific Sanddab	0.03(0.02-0.05)	0.03(0.02-0.04)	0.02(0.02-0.03)	0.06(0.02-0.08)
Ca.Scorpionfish	0.04(0.03-0.09)	0.07(0.07-0.09)	0.04(0.02-0.11)	
Calif. Halibut	<0.01(<0.02)**		<0.02(<0.01-0.03)**	
Bocaccio	<0.01(<0.01-0.03)	0.02(0.02-0.03)		0.01(<0.01-0.03)
Kelp Bass		0.02(0.02-0.03)		0.02(<0.02-0.03)

* Based on OES analyses

Table B-4a. Cont.

ORGANISM	COPPER			
	JWPCP	OCSD	COASTAL CONTROL	ISLAND CONTROL
Red Sea Urchin	0.27(0.23-0.38)			0.26(0.19-0.34)**
Black Abalone	3.4 (1.8 -4.4)*			3.9 (1.5 -5.9)*
Ridgeback Prawn	2.0 (0.06-2.3)	8.0 (2.2- 10)		
Yellow Crab	7.9 (2.5 -22)*		13 (3.6 -15)	
Spiny Lobster	6.1 (3.2 -16)*		6.4 (2.5 -37)*	14 (8.3 -33)*
White Croaker	0.21(0.09-0.50)*	0.17(0.09-0.95)*	0.11(0.09-0.20)*	
Pacific Sanddab	0.20(0.14-0.63)*	0.09(0.06-0.84)*		0.17(0.09-0.37)*
Ca.Scorpionfish	0.15(0.07-0.85)*	0.10(<0.04-0.23)*	0.15(0.10-0.19)*	
Calif. Halibut	0.13(0.05-0.21)**		<0.02(<0.03)**	
Bocaccio	0.15(0.06-4.3)*			0.13(0.11-0.31)
Kelp Bass		0.19(0.17-0.19)		0.13(0.06-0.30)

* Based on OES analyses

** [illegible]

Table B-4a. Cont.

ORGANISM	NICKEL JWPCP	OCSD	COASTAL CONTROL	ISLAND CONTROL
Red Sea Urchin	0.12(<0.02-0.13)			0.04(0.04-0.05)**
Black Abalone	0.68(0.50-2.0)			0.20(0.14-0.62)
Ridgeback Prawn	<0.03(<0.03-0.04)	<0.04(<0.02-0.06)	0.04(<0.07-0.06)	
Yellow Crab	0.26(0.22-0.51)		<0.04(<0.05)	
Spiny Lobster	<0.05(<0.05)		<0.05(<0.05)	<0.06(<0.08)
White Croaker	0.42(0.37-0.65)	0.16(0.15-0.26)	0.61(0.19-0.67)	
Pacific Sanddab	0.06(0.04-0.06)	0.05(0.03-0.24)	0.04(<0.06-0.06)	0.08(0.07-0.27)
Ca.Scorpionfish	0.15(0.07-0.21)	0.85(0.41-0.85)	0.11(0.10-0.19)	
Calif. Halibut	<0.02(<0.03)**		<0.01(<0.01)**	
Bocaccio	0.06(<0.04-0.07)	0.04(<0.03-0.07)		<0.05(<0.04-0.05)
Kelp Bass		0.06(0.03-0.11)		0.04(<0.03-0.12)

* Based on OES analyses

** n = 2

Table B-4a. Cont.

ORGANISM	LEAD			
	JWPCP	OCSD	COASTAL CONTROL	ISLAND CONTROL
Red Sea Urchin	<0.01(<0.02)			<0.01(<0.02)**
Black Abalone	<0.12(<0.14)			<0.08(<0.23)
Ridgeback Prawn	<0.01(<0.01-0.05)	<0.12(<0.21)	0.16(0.05-0.43)	
Yellow Crab	0.14(0.03-0.45)		<0.15(<0.16)	
Spiny Lobster	<0.23(<0.26)		<0.20(<0.20-0.09)	<0.21(<0.10-0.21)
White Croaker	0.29(0.17-1.0)	0.41(0.35-0.46)	0.71(0.25-0.72)	
Pacific Sanddab	0.02(<0.01-0.24)	0.03(0.01-0.06)	0.28(<0.02-0.39)	0.24(0.24-0.74)
Ca.Scorpionfish	0.64(0.58-1.6)	2.0 (1.5 -2.0)	1.1 (0.92-1.5)	
Calif. Halibut	<0.01(<0.02)**		<0.01(<0.01)**	
Bocaccio	0.08(0.08-0.23)	0.20(0.09-0.24)		<0.08(<0.24)
Kelp Bass		<0.01(<0.01)		<0.01(<0.01)

* Based on OES analyses

** n = 2

Table B-4a. Cont.

ORGANISM	ZINC			
	JWPCP	OCSD	COASTAL CONTROL	ISLAND CONTROL
Red Sea Urchin	4.2 (2.8 -41)			11.2(2.4-20)**
Black Abalone	13 (5.1 -43)*			7.1 (4.3 -11)*
Ridgeback Prawn	9.8 (4.0 -9.9)	13 (11 -18)		
Yellow Crab	25 (20 -39)*		97 (34 -210)	
Spiny Lobster	8.6 (6.0 -11)*		11 (9.2 -13)*	14 (11 -22)*
White Croaker	3.6 (2.0 -6.4)*	3.0 (2.4 -5.2)*	1.3 (1.1 -1.9)*	
Pacific Sanddab	3.2 (<1.2 -6.6)*	2.0 (1.7 -1.3)*		3.9 (2.7 -6.1)*
Ca.Scorpionfish	3.8 (2.4- 6.3)*	4.0 ('3.3 -5.6)*	1.9 (<1.2 -2.5)*	
Calif. Halibut	2.8 (2.7 -3.0)**		2.4 (2.2 -2.6)**	
Bocaccio	4.3 (3.7 -5.3)*			1.8 (1.7 -2.0)*
Kelp Bass		3.7 (3.1 -6.2)		4.8 (3.8 -4.1)

* Based on OES analyses

** n = 2

Table B-4b. Median concentrations (mg/wet kg) and ranges of mercury in edible tissue of seafood organisms collected from two outfall regions and two control regions during 1975-76.

Organism	JWPCP	OCSD	Coastal Control	Island Control
Red Sea Urchin	0.006 (n=3) (0.004-0.018)		0.026 (n=5) (0.013-0.090)	0.024 (n=3) (0.020-0.029)
Black Abalone	0.011 (n=6) (0.004-0.021)		0.010 (n=6) (<0.002-0.012)	0.009 (n=9) (0.004-0.062)
Rock Scallop	0.056 (n=3) (0.053-0.069)		0.024 (n=3) (0.018-0.032)	0.025 (n=3) (0.013-0.042)
White Squid	0.078 (n=3) (0.078-0.15)			0.054 (n=10) (0.039-0.078)
Ridgeback Prawn	0.080 (n=5) (0.062-0.083)	0.040 (n=10) (0.026-0.051)		0.046 (n=10) (0.023-0.089)
Yellow Crab	0.034 (n=4) (0.023-0.10)	0.10 (n=7) (0.056-0.21)	0.071 (n=3) (0.068-0.17)	
Spiny Lobster	0.28 (n=6) (0.21 - 0.48)		0.28 (n=3) (0.092-0.29)	0.25 (n=3) (0.20 - 0.38)
White Croaker	0.048 (n=3) (0.039-0.34)	0.18 (n=3) (0.17 -0.20)	0.33 (n=3) (0.29 -0.33)	
Pacific Sanddab	0.095 (n=3) (0.072-0.12)	0.11 (n=10) (0.083-0.19)		0.072 (n=3) (0.053-0.16)
Calif. Scorpionfish	0.38 (n=4) (0.22 -0.78)	0.28 (n=10) (0.17 -0.82)		0.24 (n=3) (0.22 -0.39)
Northern Anchovy	0.077 (n=10) (0.062-0.12)	0.078 (n=9) (0.030-0.12)		0.067 (n=10) (0.022-0.12)
Calif. Halibut	0.25 (n=4) (0.19- 0.50)	0.25 (n=3) (0.24 -0.36)	0.22 (n=2) (0.20 -0.24)	
Boccacio	0.14 (n=3) (0.11 -0.19)	0.13 (n=3) (0.11 -0.15)		0.32 (n=3) (0.27 -0.33)
Barred Sandbass		0.40 (n=10) (0.20 -0.65)		
Kelp Bass	0.45 (n=4) (0.19 -2.2)	0.36 (n=10) (0.12 - 1.1)		0.43 (n=5) (0.077-0.50)
Pacific Bonito	0.37 (n=3) (0.27 -0.38)	0.24 (n=7) (0.12 -0.45)		

Table B- 5. Median concentrations (mg/dry kg) and ranges of seven trace metals measured by OES in tissues of seafood organisms collected from two outfall and two control regions during 1975-76.
In the following table ND denotes not detected; ** denotes detected but not quantifiable, less than the following lower limits (ppm): Ag, 0.1; Cd, 3.0; Cr, 0.2; Cu, 0.2; Ni, 2.0; Pb, 1.0; Zn, 5.0. M denotes greater than the upper limits of detection (ppm): Ag, 100; Cu, 1,000. For genus and species of organisms, see Table 1.

SILVER

Sample Description	JWPCP			OCSD			Coastal Control			Island Control		
	n	med	range	n	med	range	n	med	range	n	med	range
Sea urchin												
Gonad	5	0.3	0.3-0.5				8	0.6	0.2-0.9	10	0.5	0.2-0.7
Abalone												
Muscle	5	0.4	0.3-0.8				4	1.7	0.5-2.7	10	0.4	0.3-1.1
Viscera	5	21.6	1.1-80.2				5	59.6	14.6-M	9	0.9	ND -43.2
Scallop												
Muscle	10	0.5	0.4-1.0				10	0.5	0.4-0.6	17	0.8	0.5-1.5
Gonad										6	1.0	0.7-1.2
Squid												
Muscle	10	0.6	0.3-1.2							10	0.7	0.5-1.0
Prawn												
Muscle	10	0.7	0.5-3.5	10	1.0	0.7-2.9				10	0.5	0.4-0.5
Crab												
Muscle	9	2.3	1.1-4.3	3	3.5	0.9-10.0	9	1.4	0.3-12.3			
Lobster												
Muscle	5	0.5	0.2-0.6				6	0.5	0.2-2.9	10	0.4	0.2-1.0
Digestive Gland	5	47.1	31.7-65.2				6	67.7	33.1-M	10	36.8	15.5-M
Green Gland	5	2.2	1.4-5.3				6	5.2	1.2-21.4	10	34.4	16.1-M
Gonad	5	1.1	0.5-3.1				6	1.3	0.5-4.1	10	0.7	0.3-11.0

SILVER

Sample Description	JWPCP			OCSD			Coastal Control			Island Control		
	n	med	range	n	med	range	n	med	range	n	med	range
Croaker												
Muscle	12	0.5	0.2-1.3	10	0.3	0.3-0.4	5	0.3	0.2-0.5			
Liver	3	0.9	0.7-1.9	10	1.6	0.5-10.6	5	4.8	4.4-6.7			
Kidney	13	1.4	0.6-25.1	10	1.0	ND- 5.2	5	0.6	ND -1.8			
Gonad	12	0.9	0.3-1.6	10	0.5	0.4-0.7	5	0.4	0.4-0.6			
Skin	13	0.8	0.3-2.8	10	0.2	0.1-1.1	5	0.5	0.4-0.5			
Sanddab												
Muscle	10	0.8	0.4-1.4	6	0.4	0.4-0.5				10	1.0	0.6-1.4
Liver												
Kidney	8	1.2	0.8-2.4	5	1.2	1.1-1.3						
Gonad	8	1.3	1.0-2.4									
Skin	9	1.1	1.0-1.7									
Scorpionfish												
Muscle	9	0.3	0.2-0.9	10	0.3	0.2-0.3	5	0.5	0.3-0.5	3	0.3	0.2-0.3
Liver	5	0.6	0.5-1.4	10	0.5	0.4-2.0	5	3.2	1.7-5.4	3	0.4	0.4-0.5
Kidney	9	0.9	0.5-2.6	10	0.5	0.3-1.7	5	0.5	0.4-0.7	3	0.4	0.3-0.5
Gonad	6	0.9	0.3-2.3	10	0.7	0.3-21.7	3	0.5	0.5-16.5	3	0.6	0.5-0.6
Skin	8	0.4	0.2-1.7	9	0.4	0.2-0.5	4	0.4	0.3-0.4	3	0.3	0.3-0.3
Anchovy												
Muscle	10	0.4	0.3-0.5	10	0.4	0.3-0.5	5	0.4	0.3-0.5	10	0.4	0.3-0.4
Halibut												
Muscle	4	0.4	0.3-0.5	5	0.3	0.3-0.4	2	0.3	0.3-0.3			
Liver	4	0.6	0.5-2.5	5	0.6	0.5-1.0						
Kidney	4	0.4	0.3-0.6									
Gonad	4	0.6	0.4-0.6	5	0.5	0.4-0.6						
Skin	4	0.4	0.3-0.4	5	0.4	0.3-0.4						

SILVER

Sample Description	JWPCP			OCSD			Coastal Control			Island Control		
	n	med	range	n	med	range	n	med	range	n	med	range
Bocaccio												
Muscle	8	0.4	0.3-1.4							3	0.2	0.2-0.3
Liver	3	0.3	0.3-0.4							3	0.2	0.2-0.3
Kidney	10	0.9	0.2-1.8							3	0.3	0.2-0.3
Gonad	10	0.6	0.3-2.0							3	0.5	0.5-0.5
Skin	9	1.0	0.3-2.3							3	0.4	0.3-0.4
Sanddabs												
Muscle				10	0.4	0.4-0.5						
Kelp Bass												
Muscle	4	0.4	0.3-0.4	10	0.4	0.2-0.5				9	0.5	0.2-1.3
Liver	4	0.2	** -0.3	10	0.4	0.2-0.4				5	0.2	ND -0.3
Kidney	4	0.4	0.3-0.4	10	0.5	0.4-0.7				9	0.5	0.4-1.4
Gonad	4	0.6	0.6-0.8	10	0.5	0.3-1.6				10	0.6	0.3-1.3
Skin	4	0.3	0.3-0.4	10	0.3	0.2-3.2				9	1.0	0.7-2.0
Bonito												
Muscle	3	0.5	0.4-0.6	7	0.2	0.1-0.5						

CADMIUM

Sample Description	JWPCP			OCSD			Coastal Control			Island Control		
	n	med	range	n	med	range	n	med	range	n	med	range
Sea urchin												
Gonad	5	**	**-**				8	**	ND-**	10	**	ND-6.9
Abalone												
Muscle	5	**	**- 3.1				4	**	**-**	10	**	**-**
Viscera	5	85.5	4.7-161.0				5	159.0	22.4-340.0	9	237.0	**-617.0
Scallop												
Muscle	10	**	ND-**				10	ND	ND-3.1	17	**	ND-**
Gonad										6	<4.3	**-5.3
Squid												
Muscle	10	ND	ND-**							10	**	ND-**
Prawn												
Muscle	10	ND	ND-**	10	**	ND-**				10	**	ND-**
Crab												
Muscle	9	**	ND-27.7	3	ND	ND-**	9	**	ND-**			
Lobster												
Muscle	5	**	ND-**				6	**	**-**	10	**	**-**
Digestive Gland	5	9.9	5.3-15.1				6	15.0	4.0-29.9	10	5.8	**-153.0
Green Gland	5	36.0	11.8-74.4				6	18.0	** -49.5	10	7.9	**-59.0
Gonad	5	**	**-**				6	**	** -3.2	10	**	ND-139.0

CADMIUM

Sample Description	JWPCP			OCSD			Coastal Control			Island Control		
	n	med	range	n	med	range	n	med	range	n	med	range
Croaker												
Muscle	12	**	**-**	10	ND	ND-ND	5	**	**-**			
Liver	3	4.9	4.5-21.8	10	**	**-7.8	5	12.9	11.1-19.5			
Kidney	13	**	**-12.2	10	4.4	**-9.2	5	5.4	4.6-10.6			
Gonad	12	**	**-5.4	10	**	**-3.9	5	5.4	**-5.7			
Skin	13	**	**-8.9	10	ND	ND-**	5	**	**-**			
Sanddab												
Muscle	10	**	ND-**	6	ND	ND-ND				10	**	ND-**
Liver												
Kidney	8	**	ND-**	5	**	**-**						
Gonad	8	**	ND-**									
Skin	9	**	ND-17.6									
Scorpionfish												
Muscle	9	ND	ND-**	10	ND	ND-**	5	**	ND-**	3	**	ND-**
Liver	5	ND	ND-**	10	ND	ND-**	5	**	**-5.2	3	ND	ND-**
Kidney	9	**	ND-**	10	**	ND-**	5	**	**-**	3	**	**-**
Gonad	6	**	**-3.4	10	**	ND-8.3	3	**	ND-31.0	3	**	ND-**
Skin	8	**	**-**	9	ND	ND-ND	4	**	ND-**	3	ND	ND-ND
Anchovy												
Muscle	10	ND	ND-**	10	ND	ND-**	5	**	ND-**	10	**	ND-**
Halibut												
Muscle	4	**	ND-**	5	ND	ND-**	2	**	**-**			
Liver	4	3.4	**-3.7	5	ND	ND-ND						
Kidney	4	**	**-**									
Gonad	4	**	ND-**	5	ND	ND-**						
Skin	4	ND	ND-**	5	ND	ND-ND						

CADMIUM

Sample Description	JWPCP			OCSD			Coastal Control			Island Control		
	n	med	range	n	med	range	n	med	range	n	med	range
Bocaccio												
Muscle	8	**	ND-**							3	**	**-**
Liver	3	ND	ND-**							3	9.2	7.4-11.2
Kidney	10	**	ND-**							3	**	**-**
Gonad	10	**	ND-**							3	**	**-**
Skin	9	**	ND-37.0							3	**	**-**
Sanddabs												
Muscle				10	ND	ND-ND						
Kelp Bass												
Muscle	4	ND	ND-**	10	ND	ND-ND				9	ND	ND-**
Liver	4	<4.2	**-7.8	10	< 2.9	**-9.2				5	7.3	4.3-22.0
Kidney	4	**	ND-5.7	10	**	ND-**				9	**	ND-**
Gonad	4	ND	ND-**	10	**	ND-3.2				10	**	ND-4.2
Skin	4	ND	ND-4.2	10	ND	ND-ND				9	ND	ND-**
Bonito												
Muscle	3	ND	ND-ND	7	ND	ND-ND						

COPPER

Sample Description	JWPCP			OCSD			Coastal Control			Island Control		
	n	med	range	n	med	range	n	med	range	n	med	range
Sea urchin												
Gonad	5	1.2	1.0-1.4				8	2.3	1.4-6.9	10	1.7	0.7-3.1
Abalone												
Muscle	5	16.7	8.9-21.9				4	27.8	17.4-35.6	10	17.3	6.7-26.1
Viscera	5	34.5	14.4-126.0				5	136.0	75.1-146.0	9	26.2	8.0-82.4
Scallop												
Muscle	10	1.5	0.9-4.9				10	0.8	0.5-2.5	17	1.5	0.7-10.8
Gonad										6	8.8	3.3-11.8
Squid												
Muscle	10	13.8	5.5-25.4							10	69.7	18.8-159.0
Prawn												
Muscle	10	38.5	11.1-52.2	10	47.9	30.4-65.3				10	45.7	19.2-63.0
Crab												
Muscle	9	49.0	15.3-136.0	3	48.1	9.4-73.0	9	15.6	1.2-157.0			
Lobster												
Muscle	5	29.1	15.1-75.4				6	30.5	12.1-178.0	10	76.4	44.7-176.0
Digestive Gland	5	793.0	597.0-M				6	M	733.0-M	10	>846	179.0-M
Green Gland	5	125.0	108.0-267.0				6	105.0	59.0-275.0	10	>639	214.0-M
Gonad	5	140.0	72.6-760.0				6	299.0	123.0-643.0	10	202.0	72.7-M

COPPER

Sample Description	JWPCP			OCSD			Coastal Control			Island Control		
	n	med	range	n	med	range	n	med	range	n	med	range
Croaker												
Muscle	12	1.2	0.5-2.8	10	0.9	0.5-5.1	5	0.7	0.6-1.3			
Liver	3	8.1	7.7-36.7	10	26.6	10.2-474.0	5	78.4	61.2-206.0			
Kidney	13	6.0	3.4-16.0	10	6.6	4.8-14.8	5	7.3	6.2-9.4			
Gonad	12	3.2	1.3-6.4	10	6.8	2.5-12.8	5	2.8	1.8-3.8			
Skin	13	2.1	1.3-24.5	10	2.1	0.8-6.5	5	1.3	0.6-3.2			
Sanddab												
Muscle	10	1.2	0.8-3.7	6	0.6	0.4-5.5				10	1.1	0.6-2.4
Liver												
Kidney	8	5.3	1.7-10.5	5	5.3	3.6-11.3						
Gonad	8	3.4	1.9-38.5									
Skin	9	3.1	1.3-10.7									
Scorpionfish												
Muscle	9	0.8	0.4-4.6	10	0.5	**-1.2	5	0.9	0.6-1.1	3	0.5	0.5-2.2
Liver	5	17.7	7.4-48.1	10	13.7	6.2-44.3	5	50.8	27.6-99.6	3	205.0	189.0-214.0
Kidney	9	7.2	3.2-18.4	10	5.6	3.3-9.7	5	3.4	3.1-3.9	3	5.5	5.1-13.7
Gonad	6	6.0	0.4-58.4	10	11.4	3.1-165.0	3	3.9	0.7-56.6	3	11.7	2.2-15.2
Skin	8	2.7	1.0-5.3	9	2.4	1.4-3.3	4	1.4	0.9-1.6	3	1.6	0.7-1.9
Anchovy												
Muscle	10	2.1	1.8-8.0	10	2.9	1.3-3.3	5	1.3	1.2-2.5	10	2.1	1.8-4.8
Halibut												
Muscle	4	0.4	0.4-0.7	5	1.0	0.3-3.7	2	0.8	0.6-0.9			
Liver	4	65.2	20.5-88.8	5	52.0	18.5-64.6						
Kidney	4	4.6	3.3-9.1									
Gonad	4	6.8	1.6-9.3	5	3.6	2.3-9.2						
Skin	4	0.9	0.7-2.0	5	1.7	1.4-2.5						

COPPER

Sample Description	JWPCP			OCSD			Coastal Control			Island Control		
	n	med	range	n	med	range	n	med	range	n	med	range
Bocaccio												
Muscle	8	0.6	0.3-1.5							3	0.8	0.7-1.9
Liver	3	9.9	5.5-12.5							3	49.3	28.1-65.4
Kidney	10	3.9	2.5-7.0							3	2.5	2.4-2.7
Gonad	10	1.6	0.7-12.7							3	4.3	4.3-5.0
Skin	9	2.0	1.2-6.7							3	1.6	1.0-1.6
Sanddabs												
Muscle				10	0.6	0.4-1.5						
Kelp Bass												
Muscle	4	0.4	0.3-0.5	10	0.9	0.3-7.9				9	0.6	0.2-0.9
Liver	4	3.8	1.8-8.8	10	7.2	3.8-16.9				5	6.5	3.0-14.0
Kidney	4	6.6	3.9-7.2	10	6.4	4.3-38.6				9	4.5	2.0-6.2
Gonad	4	2.6	1.3-3.3	10	12.2	3.4-71.5				10	2.0	1.3-7.7
Skin	4	1.4	1.1-1.9	10	3.2	1.4-10.8				9	0.9	0.4-3.9
Bonito												
Muscle	3	1.5	1.1-1.7	7	1.8	1.7-3.0						

CHROMIUM

Sample Description	JWPCP			OCSD			Coastal Control			Island Control		
	n	med	range	n	med	range	n	med	range	n	med	range
Sea urchin												
Gonad	5	ND	ND-ND				8	< 0.3	ND-0.6	10	1.4	ND-8.4
Abalone												
Muscle	5	3.3	2.3-6.1				4	0.5	0.3-3.1	10	0.6	**-1.5
Viscera	5	18.4	**-22.4				5	6.1	3.0-8.2	9	3.6	ND-7.3
Scallop												
Muscle	10	1.6	1.0-15.0				10	0.6	ND-3.0	17	ND	ND-4.1
Gonad										6	2.3	ND-4.0
Squid												
Muscle	10	ND	ND-14.0							10	ND	ND-ND
Prawn												
Muscle	10	**	ND-2.1	10	ND	ND-ND				10	**	ND-0.8
Crab												
Muscle	9	ND	ND-ND	3	ND	ND-ND	9	**	ND-11.9			
Lobster												
Muscle	5	ND	ND-ND				6	ND	ND-ND	10	ND	ND-**
Digestive Gland	5	**	ND-0.3				6	ND	ND-**	10	ND	ND-**
Green Gland	5	**	ND-0.2				6	ND	ND-0.3	10	ND	ND-**
Gonad	5	ND	ND-**				6	ND	ND-**	10	ND	ND-**

CHROMIUM

Sample Description	JWPCP			OCSD			Coastal Control			Island Control		
	n	med	range	n	med	range	n	med	range	n	med	range
Croaker												
Muscle	12	ND	ND-0.5	10	ND	ND-0.2	5	ND	ND-ND			
Liver	3	ND	ND-ND	10	**	ND-0.4	5	ND	ND-ND			
Kidney	13	ND	ND-10.8	10	<0.2	**-0.3	5	ND	ND-ND			
Gonad	12	ND	ND-0.2	10	ND	ND-0.2	5	ND	ND-0.3			
Skin	13	2.0	ND-31.2	10	1.6	**-5.4	5	0.5	0.2-0.8			
Sanddab												
Muscle	10	ND	ND-5.5	6	**	ND-**				10	ND	ND-2.8
Liver												
Kidney	8	ND	ND-1.1	5	ND	ND-ND						
Gonad	8	ND	ND-ND									
Skin	9	0.7	**-1.7									
Scorpionfish												
Muscle	9	ND	ND-**	10	ND	ND-**	5	ND	ND-ND	3	ND	ND-ND
Liver	5	ND	ND-**	10	ND	ND-**	5	ND	ND-ND	3	ND	ND-**
Kidney	9	ND	ND-ND	10	ND	ND-0.4	5	ND	ND-ND	3	ND	ND-ND
Gonad	6	ND	ND-0.5	10	ND	ND-ND	3	ND	ND-0.2	3	ND	ND-ND
Skin	8	1.4	**-4.9	9	3.8	0.9-6.3	4	**	ND-**	3	0.5	0.3-1.1
Anchovy												
Muscle	10	ND	ND-ND	10	ND	ND-ND	5	ND	ND-ND	10	ND	ND-ND
Halibut												
Muscle	4	ND	ND-ND	5	ND	ND-ND	2	ND	ND-ND			
Liver	4	ND	ND-ND	5	ND	ND-ND						
Kidney	4	ND	ND-ND									
Gonad	4	ND	ND-7.9	5	ND	ND-ND						
Skin	4	0.4	**-0.8	5	0.7	0.4-1.4						

CHROMIUM

Sample Description	JWPCP			OCSD			Coastal Control			Island Control		
	n	med	range	n	med	range	n	med	range	n	med	range
Bocaccio												
Muscle	8	ND	ND-**							3	ND	ND-ND
Liver	3	ND	ND-ND							3	ND	ND-ND
Kidney	10	ND	ND-ND							3	ND	ND-ND
Gonad	10	ND	ND-**							3	0.2	ND-0.2
Skin	9	**	ND-2.7							3	ND	ND-0.3
Sanddabs												
Muscle				10	ND	ND-ND						
Kelp Bass												
Muscle	4	ND	ND-ND	10	ND	ND-0.2				9	ND	ND-ND
Liver	4	ND	ND-ND	10	ND	ND-ND				5	ND	ND-ND
Kidney	4	ND	ND-ND	10	ND	ND-2.1				9	ND	ND-2.4
Gonad	4	ND	ND-ND	10	ND	ND-ND				10	ND	ND-ND
Skin	4	1.1	0.8-6.6	10	0.8	**-1.7				9	1.2	0.4-7.6
Bonito												
Muscle	3	ND	ND-ND	7	ND	ND-ND						

NICKEL

Sample Description	JWPCP			OCSD			Coastal Control			Island Control		
	n	med	range	n	med	range	n	med	range	n	med	range
Sea urchin												
Gonad	5	0.5	ND-0.6				8	ND	ND-**	10	**	ND-7.6
Abalone												
Muscle	5	2.4	ND-2.8				4	**	**-4.0	10	**	**-2.7
Viscera	5	6.7	5.2-17.4				5	5.6	3.1-7.7	9	3.8	2.6-10.9
Scallop												
Muscle	10	**	ND-**				10	ND	ND-**	17	**	ND-4.0
Gonad										6	2.2	**-3.6
Squid												
Muscle	10	**	**-5.8							10	ND	ND-ND
Prawn												
Muscle	10	**	**-10.5	10	ND	ND-**				10	ND	ND-**
Crab												
Muscle	9	**	**-5.8	3	ND	ND-**	9	0.7	ND-1.3			
Lobster												
Muscle	5	ND	ND-0.6				6	**	ND-**	10	ND	ND-ND
Digestive Gland	5	**	ND-1.5				6	2.7	1.0-6.2	10	**	ND-4.5
Green Gland	5	2.5	1.9-3.8				6	**	ND-0.7	10	**	**-4.2
Gonad	5	**	ND-0.9				6	**	ND-0.7	10	**	ND-**

NICKEL

Sample Description	JWPCP			OCSD			Coastal Control			Island Control		
	n	med	range	n	med	range	n	med	range	n	med	range
Croaker												
Muscle	12	**	ND-0.6	10	**	ND-**	5	ND	ND-0.9			
Liver	3	1.2	**-1.5	10	**	**-2.2	5	2.2	1.1-4.4			
Kidney	13	3.8	**-6.0	10	3.2	**-5.0	5	2.7	2.5-4.1			
Gonad	12	**	ND-0.9	10	**	ND-**	5	1.1	**-2.2			
Skin	13	**	ND-2.4	10	**	**-2.5	5	0.8	ND-1.3			
Sanddab												
Muscle	10	<2.2	**-6.4	6	**	ND-**				10	2.9	**-5.1
Liver												
Kidney	8	**	**-**	5	ND	ND-ND						
Gonad	8	**	**-4.5									
Skin	9	**	**-9.9									
Scorpionfish												
Muscle	9	**	ND-2.5	10	**	ND-**	5			3	**	ND-**
Liver	5	**	ND-**	10	**	ND-**	5			3	**	**-**
Kidney	9	**	ND-**	10	ND	ND-**	5			3	**	**-**
Gonad	6	**	ND-4.0	10	**	ND-3.8	3			3	**	**-**
Skin	8	**	**-**	9	**	**-**	4			3	**	**-**
Anchovy												
Muscle	10	ND	ND-ND	10	ND	ND-**	5	**	ND-0.6	10	ND	ND-**
Halibut												
Muscle	4	**	ND-1.7	5	**	**-**	2	**	ND-**			
Liver	4	**	ND-**	5	**	ND-**						
Kidney	4	**	ND-0.9									
Gonad	4	ND	ND-0.8	5	ND	ND-ND						
Skin	4	**	**-0.6	5	**	ND-**						

NICKEL

Sample Description	JWPCP			OCSD			Coastal Control			Island Control		
	n	med	range	n	med	range	n	med	range	n	med	range
Bocaccio												
Muscle	8	**	ND-**							3	**	**-0.9
Liver	3	**	**-**							3	ND	ND-**
Kidney	10	**	ND-7.5							3	**	ND-**
Gonad	10	**	ND-5.6							3	2.2	0.6-2.3
Skin	9	**	ND-**							3	1.9	0.8-1.9
Sanddabs												
Muscle				10	ND	ND-**						
Kelp Bass												
Muscle	4	ND	ND-**	10	ND	ND-**				9	**	ND-3.5
Liver	4	ND	ND-**	10	**	ND-**				5	ND	ND-**
Kidney	4	**	ND-**	10	ND	ND-ND				9	**	ND-4.1
Gonad	4	**	ND-**	10	ND	ND-**				10	ND	ND-3.4
Skin	4	**	**-**	10	**	**-**				9	**	**-**
Bonito												
Muscle	3	ND	ND-ND	7	**	ND-**						

LEAD

Sample Description	JWPCP			OCSD			Coastal Control			Island Control		
	n	med	range	n	med	range	n	med	range	n	med	range
Sea urchin												
Gonad	5	1.2	**-2.3				8	ND	ND-**	10	ND	ND-**
Abalone												
Muscle	5	**	ND-1.2				4	ND	ND-ND	10	ND	ND-ND
Viscera	5	11.2	ND-37.6				5	18.9	ND-162.0	9	26.5	ND-38.9
Scallop												
Muscle	10	ND	ND-ND				10	ND	ND-ND	17	ND	ND-**
Gonad										6	**	ND-**
Squid												
Muscle	10	**	**-4.9							10	ND	ND-ND
Prawn												
Muscle	10	**	ND-**	10	ND	ND-ND				10	ND	ND-**
Crab												
Muscle	9	**	ND-**	3	ND	ND-ND	9	3.6	2.4-90.0			
Lobster												
Muscle	5	2.6	1.5-2.8				6	3.5	**-4.5	10	**	ND-**
Digestive Gland	5	ND	ND-ND				6	ND	ND-1.0	10	ND	ND-**
Green Gland	5	1.2	**-2.0				6	1.2	ND-2.4	10	**	**-**
Gonad	5	3.3	2.3-3.8				6	3.2	**-3.5	10	**	ND-2.1

LEAD

Sample Description	JWPCP			OCSD			Coastal Control			Island Control		
	n	med	range	n	med	range	n	med	range	n	med	range
Croaker												
Muscle	12	ND	ND-**	10	ND	ND-**	5	2.1	2.0-2.6			
Liver	3	ND	ND-**	10	**	ND-**	5	2.2	**-5.8			
Kidney	13	2.1	**-19.1	10	12.9	**-41.1	5	9.2	4.1-17.6			
Gonad	12	ND	ND-3.6	10	ND	ND-ND	5	2.2	**-2.3			
Skin	13	ND	ND-3.3	10	**	**-**	5	**	ND-2.0			
Sanddab												
Muscle	10	**	ND-**	6	ND	ND-ND				10	**	**-**
Liver												
Kidney	8	3.3	ND-24.7	5	ND	ND-ND						
Gonad	8	**	**-**									
Skin	9	**	ND-2.5									
Scorpionfish												
Muscle	9	ND	ND-**	10	ND	ND-ND	5	3.1	1.9-3.4	3	ND	ND-ND
Liver	5	ND	ND-ND	10	ND	ND-**	5	ND	ND-**	3	ND	ND-ND
Kidney	9	ND	ND-ND	10	ND	ND-ND	5	ND	ND-**	3	ND	ND-ND
Gonad	6	ND	ND-**	10	ND	ND-**	3	2.6	ND-3.0	3	ND	ND-ND
Skin	8	**	ND-2.2	9	1.2	**-2.2	4	2.6	1.4-3.2	3	**	**-**
Anchovy												
Muscle	10	ND	ND-ND	10	ND	ND-ND	5	3.0	2.8-4.4	10	ND	ND-**
Halibut												
Muscle	4	**	ND-1.1	5	ND	ND-ND	2	3.4	3.1-3.7			
Liver	4	ND	ND-ND	5	ND	ND-ND						
Kidney	4	**	ND-**									
Gonad	4	<4.2	ND-4.9	5	ND	ND-ND						
Skin	4	<1.3	**-1.3	5	ND	ND-**						

LEAD

Sample Description	JWPCP			OCSD			Coastal Control			Island Control		
	n	med	range	n	med	range	n	med	range	n	med	range
Bocaccio												
Muscle	8	ND	ND-ND							3	2.7	2.6-3.9
Liver	3	ND	ND-ND							3	ND	ND-5.7
Kidney	10	ND	ND-ND							3	**	**-**
Gonad	10	ND	ND-**							3	4.4	3.8-5.2
Skin	9	ND	ND-4.4							3	2.4	1.2-2.8
Sanddabs												
Muscle				10	ND	ND-**						
Kelp Bass												
Muscle	4	ND	ND-ND	10	ND	ND-**				9	ND	ND-**
Liver	4	ND	ND-ND	10	**	ND-1.0				5	ND	ND-**
Kidney	4	ND	ND-ND	10	ND	ND-1.8				9	ND	ND-**
Gonad	4	ND	ND-ND	10	ND	ND-10.7				10	**	ND-1.6
Skin	4	**	**-1.4	10	**	ND-1.1				9	ND	ND-4.1
Bonito												
Muscle	3	ND	ND-6.0	7	ND	ND-ND						

ZINC

Sample Description	JWPCP			OCSD			Coastal Control			Island Control		
	n	med	range	n	med	range	n	med	range	n	med	range
Sea urchin												
Gonad	5	28.0	5.3-33.7				8	45.3	19.3-167.0	10	25.0	10.2-236.0
Abalone												
Muscle	5	45.2	17.5-148.0				4	32.0	26.2-35.2	10	24.4	14.8-37.3
Viscera	5	20.5	14.4-22.2				5	223.0	131.0-496.0	9	118.0	36.8-283.0
Scallop												
Muscle	10	49.5	35.7-65.6				10	60.8	23.7-43.4	17	38.8	23.4-79.0
Gonad										6	47.9	31.4-77.8
Squid												
Muscle	10	25.0	11.6-59.1							10	35.6	26.4-46.9
Prawn												
Muscle	10	30.0	16.4-39.6	10	28.1	24.7-39.9				10	30.6	23.9-50.6
Crab												
Muscle	9	106.0	87.3-167.0	3	118.0	82.7-150.0	9	73.8	**-151.0			
Lobster												
Muscle	5	28.5	19.8-36.5				6	36.4	30.6-41.9	10	52.5	41.3-81.9
Digestive Gland	5	80.9	54.0-120.0				6	96.2	63.0-226.0	10	89.4	51.3-376.0
Green Gland	5	43.6	35.9-63.2				6	41.0	28.8-83.7	10	99.3	55.5-453.0
Gonad	5	17.7	14.4-28.6				6	14.7	10.4-46.3	10	49.8	14.9-190.0

ZINC

Sample Description	JWPCP			OCSD			Coastal Control			Island Control		
	n	med	range	n	med	range	n	med	range	n	med	range
Croaker												
Muscle	12	14.2	7.8-25.1	10	11.4	9.1-19.3	5	6.1	5.2-8.6			
Liver	3	48.4	38.4-59.8	10	52.0	27.5-75.2	5	65.8	54.9-125.0			
Kidney	13	57.8	43.8-85.2	10	63.6	45.5-93.4	5	43.7	40.5-60.5			
Gonad	12	141.5	36.5-369.0	10	184.0	57.7-394.0	5	50.5	33.2-295.0			
Skin	13	47.4	19.5-166.0	10	11.7	9.3-41.2	5	29.9	13.1-78.0			
Sanddab												
Muscle	10	13.2	**-26.9	6	9.3	7.9-14.2				10	17.5	12.4-27.8
Liver												
Kidney	8	46.0	21.9-85.0	5	72.8	63.5-79.1						
Gonad	8	143.9	35.6-327.0									
Skin	9	38.2	23.4-61.1									
Scorpionfish												
Muscle	9	14.3	8.9-23.7	10	14.2	11.8-20.0	5	7.6	**-10.3	3	11.9	10.2-16.1
Liver	5	25.7	16.8-41.7	10	34.6	20.3-67.8	5	102.0	54.8-129.0	3	29.5	22.7-43.3
Kidney	9	70.9	51.8-99.3	10	74.0	56.4-84.1	5	47.1	39.5-48.4	3	76.3	67.7-92.8
Gonad	6	55.2	7.5-174.0	10	75.0	30.9-352.0	3	58.8	**-234.0	3	67.4	34.7-95.0
Skin	8	21.8	9.1-59.9	9	13.4	9.6-25.2	4	9.7	6.5-44.8	3	8.4	5.9-27.7
Anchovy												
Muscle	10	33.4	11.2-87.6	10	38.0	19.2-66.8	5	10.0	7.0-20.1	10	40.6	20.9-63.3
Halibut												
Muscle	4	8.0	5.8-16.8	5	16.1	10.0-27.0	2	6.8	6.8-6.9			
Liver	4	101.0	84.0-268.0	5	70.4	54.1-163.0						
Kidney	4	100.2	37.7-88.8									
Gonad	4	53.0	23.0-238.0	5	56.7	46.2-77.5						
Skin	4	22.9	15.0-31.9	5	30.0	27.2-39.6						

ZINC

Sample Description	JWPCP			OCSD			Coastal Control			Island Control		
	n	med	range	n	med	range	n	med	range	n	med	range
Bocaccio												
Muscle	8	13.3	11.5-16.3							3	7.6	7.3-8.5
Liver	3	32.0	30.8-53.3							3	131.0	127.0-149.0
Kidney	10	51.8	**-73.3							3	23.0	20.7-24.8
Gonad	10	24.6	9.7-266.0							3	56.4	27.1-63.8
Skin	9	26.3	7.1-81.6							3	7.8	6.9-9.2
Sanddabs												
Muscle				10	12.2	9.4-27.7						
Kelp Bass												
Muscle	4	10.9	9.5-11.2	10	13.4	9.8-43.4				9	13.6	9.7-20.4
Liver	4	43.6	20.5-65.9	10	49.2	37.9-71.9				5	73.3	36.9-104.0
Kidney	4	61.5	46.8-81.5	10	49.2	41.2-61.2				9	41.9	35.4-58.0
Gonad	4	420.0	292.0-468.0	10	45.6	29.5-495.0				10	72.5	36.9-555.0
Skin	4	16.9	14.2-33.5	10	13.2	8.9-26.7				9	18.5	7.8-114.0
Bonito												
Muscle	3	12.8	12.4-12.9	7	17.2	12.6-21.2						

Table B-6a. Mean concentrations (mg/dry kg) of cadmium, copper, and PCB 1254 in tissues of M. edulis from San Diego Harbor (Stations A-E) and La Jolla (Station F), January 1974.

Constituent	Station A	B	C	D	E	F
1254 PCB*	3.1	3.8	3.1	1.2	0.18	0.22
Cadmium						
Dig. Gland	18	< 3.8	<5.0	<9.3	< 6.1	< 4.6
Gonads	9.4	< 2.7	<3.6	6.1	< 4.0	< 3.9
Muscle	6.7	< 4.6	<3.5	6.2	< 3.5	< 4.5
Remainder	15	< 3.7	5.6	<5.6	< 3.4	6.2
Copper						
Dig. Gland	48	73	45	39	17	22
Gonads	15	23	11	12	13	9.6
Muscle	7.0	34	7.2	12	7.7	22
Remainder	17	34	15	11	12	15

* Whole soft tissues; values based on wet/dry weight ratio of 4.4

Table B-6b. Mean concentrations (± standard error) of trace elements (mg/dry kg) in six digestive gland samples of M. edulis from San Diego Harbor (Stations A-E) and in La Jolla (Station F), January 1974.

Metal	Station A	B	C	D	E	F
Silver	<2.9	<0.2	<0.1	<1.0	<0.6	<0.1
Cadmium	18±7.4	<3.8	<5.0	<9.3	<6.1	<4.6
Chromium	15±8.3	6.2±0.8	4.4±0.7	7.0±0.9	3.5±0.4	7.2±1.3
Copper	48±3.3	73±8.0	45±14	39±5.8	17±1.2	22±1.7
Nickel	7.4±2.0	5.0±1.2	<1.9	<3.5	<3.0	6.0±1.9
Lead	22±1.4	12±1.6	13±2.0	6.9±1.0	<2.3	13±1.7
Tin	3.2±0.6	3.5±0.4	1.9±0.6	2.4±0.3	<0.7	2.0±0.4
Zinc	160±17	150±18	120±19	210±25	140±18	120±7.1

Table B-6c. Mean concentration e (± standard error) of trace metals (mg/dry kg) in digestive gland (n=6), gonad (n=2), adductor muscle (n=2) and remaining tissues (n=2) of M. edulis collected from Newport Harbor and Newport Beach, January 1974.

Constituent	Tissue	Harbor	Beach	Ratio
1254 PCB	Whole soft*	3.9	0.44	8.9
Silver	Dig. Gland	< 0.3	< 0.4	-
	Gonad	< 0.7	< 0.4	-
	Muscle	< 0.4	< 0.4	-
	Remainder	< 0.8	< 0.5	-
Cadmium	Dig. Gland	10±1.9	< 4.7	> 2.1
	Gonad	9.0±9.0	< 2.8	> 3.2
	Muscle	7.1±3.4	< 3.0	> 2.4
	Remainder	7.6±0.8	< 4.8	> 1.6
Chromium	Dig. Gland	3.8±0.6	3.7±0.6	1.0
	Gonad	2.0±0.4	0.3±0.1	6.7
	Muscle	< 0.6	< 0.6	-
	Remainder	1.6±0.1	1.0±0.1	1.6
Copper	Dig. Gland	127±18	16±1.0	7.9
	Gonad	93±15	9.6±0.2	9.9
	Muscle	52±10	5.7±0.3	9.1
	Remainder	100±14	11±0.6	9.1
Nickel	Dig. Gland	< 2.7	3.6±0.7	<0.8
	Gonad	< 2.2	< 0.9	-
	Muscle	< 1.3	< 2.6	-
	Remainder	< 3.7	< 2.9	-

*Values based on wet/dry weight ratio of 4.4

Table B-6c continued

Constituent	Tissue	Harbor	Beach	Ratio
Lead	Dig. Gland	19±2.7	5.5±0.6	3.5
	Gonad	13±4.6	< 0.9	> 14
	Muscle	< 1.3	< 1.2	-
	Remainder	10±2.0	< 1.6	> 6.2
Tin	Dig. Gland	3.6±0.8	1.4±0.3	2.6
	Gonad	5.4±1.4	< 0.3	> 18
	Muscle	< 0.5	< 0.7	-
	Remainder	3.4±1.2	< 0.5	6.8
Zinc	Dig. Gland	240±26	80±11	3.0
	Gonad	360±120	87±3	4.1
	Muscle	210±66	79±3	2.7
	Remainder	280±45	99±16	2.8

Table B-6d. Mean concentrations (± standard error) of trace metals (mg/dry kg) in tissues of M. edulis from Royal Palms Beach and five other coastal sites, January 1974.

Constituent	Tissue	Royal Palms	Other Coastal	Ratio
1254 PCB	Whole Soft*	0.53	0.31±0.05	1.7
Silver	Dig. Gland	1.2±0.3	< 0.3	> 4.0
	Gonad	2.2±0.05	< 0.6	> 3.7
	Muscle	< 0.6	< 0.4	-
	Remainder	4.9±0.4	< 0.6	> 8.2
Cadmium	Dig. Gland	8.2±1.1	<6.0	> 1.4
	Gonad	< 4.6	<3.5	-
	Muscle	< 3.7	<3.4	-
	Remainder	9.2±1.4	<4.4	2.1
Chromium	Dig. Gland	15±0.9	4.8±0.7	3.1
	Gonad	1.3±0.1	0.6±0.1	2.2
	Muscle	< 1.0	<0.9	-
	Remainder	2.9±0.0	1.7±0.4	1.7
Copper	Dig. Gland	47±2.8	20±2.4	2.4
	Gonad	42±0.5	10±0.8	4.2
	Muscle	14±1.0	11±2.9	1.3
	Remainder	44±7.0	13±1.5	3.4
Nickel	Dig. Gland	10±1.4	4.1±0.7	2.4
	Gonad	< 3.0	<1.3	-
	Muscle	< 1.2	<2.0	-
	Remainder	< 3.2	<3.2	-

* Values based on wet/dry weight ratio of 4.4

Table B-6d Continued

Constituent	Tissue	Royal Palms	Other Coastal	Ratio
Lead	Dig. Gland	10±1.4	7.5±1.9	1.2
	Gonad	3.2±0.4	< 1.1	> 2.9
	Muscle	< 1.2	< 1.2	-
	Remainder	< 1.1	< 2.0	-
Tin	Dig. Gland	1.2±0.3	1.5±0.2	0.8
	Gonad	3.4±0.5	< 0.4	> 8.5
	Muscle	< 0.4	< 0.5	-
	Remainder	< 0.3	< 0.8	-
Zinc	Dig. Gland	120±14	110±10	1.1
	Gonad	120±15	93±12	1.3
	Muscle	90±42	130±27	0.9
	Remainder	140±52	140±18	1.0

APPENDIX C

CONTENTS

TABLE C-1. Average concentrations (mg/l) of eight trace metals in municipal wastewater discharged by the Los Angeles County JWPCP and Orange County OCSD Treatment Plants, 1974-76.

TABLE C-2. Estimated annual mass emission rates (metric tons/yr) of eight trace metals in municipal wastewater discharged by the Los Angeles County JWPCP and Orange County OCSD Treatment Plants, 1974-76.

Table C-1. Average concentrations (mg/l) of eight trace metals in municipal wastewater discharged by the Los Angeles County JWPCP and Orange County OCSD Treatment Plants, 1974-76. (Mitchell and McDermott 1975, Schafer 1976, Schafer 1977.)

Trace Metal	JWPCP				OCSD			
	74	75	76	$\bar{x}$	74	75	76	$\bar{x}$
Silver	0.012	0.013	0.013	0.013	0.012	0.012	0.010	0.011
Cadmium	0.041	0.036	0.026	0.034	0.061	0.040	0.040	0.047
Chromium	0.86	0.80	0.75	0.80	0.28	0.19	0.19	0.22
Copper	0.60	0.42	0.41	0.48	0.40	0.41	0.36	0.39
Mercury	0.0011	0.0011	0.0014	0.0012	NM*	NM	NM	-
Nickel	0.31	0.28	0.32	0.30	0.23	0.15	0.14	0.17
Lead	0.26	0.25	0.22	0.24	0.17	0.16	0.11	0.15
Zinc	1.8	1.4	1.3	1.50	0.54	0.65	0.54	0.58

* Not measured

Table C-2. Estimated annual mass emission rates (metric tons/yr) of eight trace metals in municipal wastewater discharged by the Los Angeles County JWPCP and Orange County OCSD Treatment Plants 1974-76. (Mitchell and McDermott 1975, Schafer 1976, Schafer 1977.)

Trace Metal	JWPCP				OCSD			
	74	75	76	$\bar{X}$	74	75	76	$\bar{X}$
Silver	5.7	6.1	6.3	6.0	2.8	2.9	2.5	2.7
Cadmium	19.6	17.0	12.8	16.5	14.4	9.7	10.1	11.4
Chromium	411	377	367	385	66.1	46.0	47.9	53.3
Copper	286	198	200	228	94.4	99.2	90.8	94.8
Mercury	0.53	0.52	0.67	0.57	NM*	NM	NM	-
Nickel	148	132	157	146	54.3	36.3	35.3	42.0
Lead	124	118	108	117	40.1	38.7	27.7	35.5
Zinc	855	683	646	728	127	157	136	140

*Not measured

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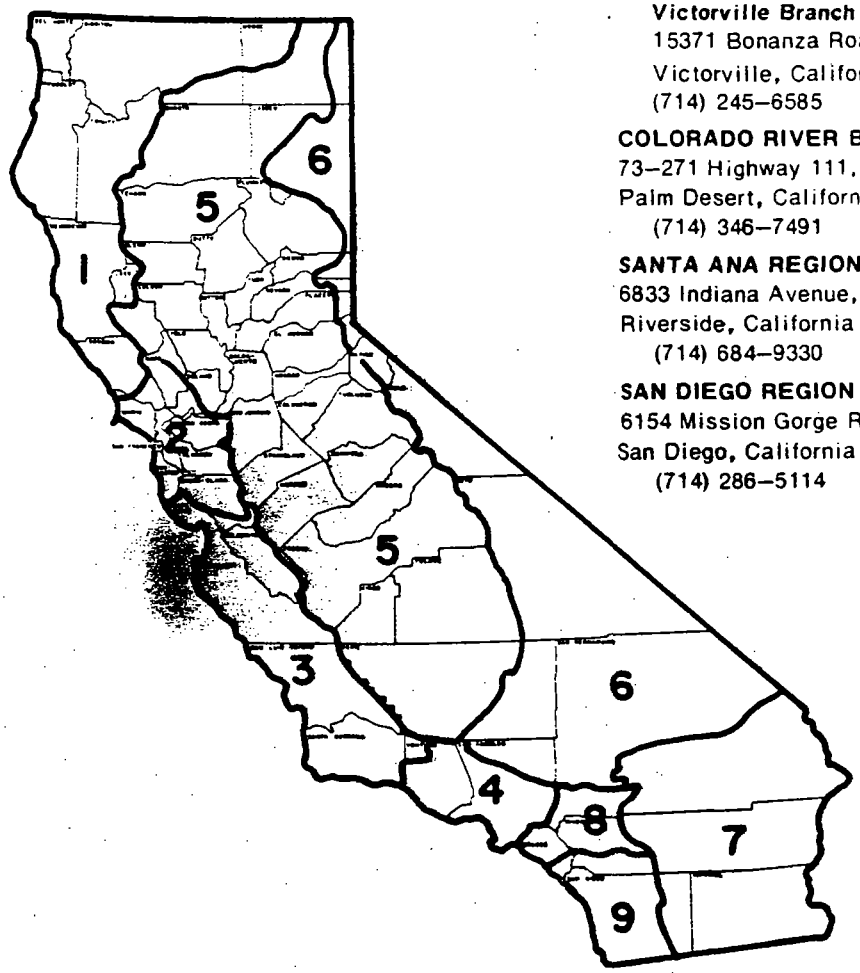

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